

PIB-0066

GA Technologies

ORNL/Sub/86-22047/2
GA-C18525

CHARACTERIZATION OF PEACH BOTTOM UNIT 1 FUEL

by
R. P. MORISSETTE, N. TOMSIO, and J. RAZVI

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Report prepared by
GA Technologies Inc.
P.O. Box 86808

San Diego, California 92138-5608
under Subcontract 86X-22047C
for Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract DE-AC05-84OR21400

NOTICE

This report contains information of a preliminary nature and was prepared primarily for internal use at the originating installation. It is subject to revision or correction and therefore does not represent a final report. It is passed to the recipient in confidence and should not be abstracted or further disclosed without the approval of the originating installation or USDOE Office of Scientific and Technical Information, Oak Ridge, TN 37830.

nfc 1/27/99

APPROVED FOR EXTERNAL RELEASE

**GA PROJECT 3442
OCTOBER 1986**

MASTER

**DISTRIBUTION OF THIS DOCUMENT IS LIMITED
TO DOE OFFICES AND DOE CONTRACTORS**

nfc 1/27/99

CONTENTS

1.	SUMMARY	1-1
2.	INTRODUCTION	2-1
3.	DESCRIPTION OF SPENT FUEL	3-1
3.1.	General Description	3-1
3.2.	Physical Description	3-4
3.2.1.	Standard Fuel Element - Core 1	3-4
3.2.2.	Instrumented Fuel Element - Core 1	3-6
3.2.3.	Standard Fuel Element - Core 2	3-9
3.2.4.	Instrumented Fuel Element - Core 2	3-9
3.2.5.	Test Fuel Elements	3-13
3.3.	Materials	3-17
3.3.1.	Nonfuel Components	3-17
3.3.2.	Fuel Assemblies	3-20
3.4.	Weights	3-22
3.4.1.	Assembly Weights	3-22
3.4.2.	Component Weights	3-23
3.4.3.	Material Weights	3-23
3.5.	Postirradiation Condition of Spent Fuel	3-24
3.5.1.	Core 1	3-24
3.5.2.	Core 2	3-24
3.6.	Packaging	3-25
3.6.1.	Core 1	3-25
3.6.2.	Core 2	3-31
4.	CURRENT INVENTORY	4-1
5.	BURNUP ANALYSIS AND ISOTOPIC COMPOSITION	5-1
5.1.	Initial Heavy Metal Loadings	5-1
5.1.1.	Core 1	5-1
5.1.2.	Core 2	5-1
5.2.	Fuel Burnup	5-7

5.3. Fuel Accountability	5-7
5.3.1. Core 1	5-7
5.3.2. Core 2 - Regular Fuel Elements	5-7
5.3.3. Core 2 - Test Elements	5-13
5.4. Fission Product Inventory	5-13
5.5. Decay Heat	5-13
6. REFERENCES	6-1
APPENDIX A: PEACH BOTTOM SPENT FUEL INVENTORY	A-1

FIGURES

3-1. Core 1 fuel element	3-2
3-2. Core 1 fuel compact assembly	3-3
3-3. Core 1 instrumented fuel element	3-8
3-4. Core 2 fuel element	3-10
3-5. Core 2 fuel compact assembly	3-11
3-6. Core 2 instrumented fuel element	3-12
3-7. Cross sections of test element classes	3-14
3-8. Typical fuel test element assembly	3-18
3-9. Typical fuel test element fuel body	3-19
3-10. Core 1 non-failed fuel element in storage canister	3-26
3-11. Core 1 fuel element in storage canister with removal tool	3-27
3-12. Core 1 failed fuel element in storage canister with removal tool in salvage canister	3-28
3-13. Core 2 storage canister.	3-32
5-1. Heat generation rate as a function of cooling time	5-17

TABLES

3-1. Uses of thermocouples in instrumented fuel elements	3-7
3-2. Peach Bottom test elements irradiated in Core 2	3-15
3-3. Core 1 fuel element composite chemical purity	3-21
3-4. Core 1 spent fuel package types	3-29

TABLES (Continued)

4-1.	Peach Bottom Unit 1 - Core 1 inventory at INEL	4-2
4-2.	Peach Bottom Unit 1 - Core 2 inventory at INEL	4-3
5-1.	Core 1 fuel element initial heavy metal loadings	5-2
5-2.	Core 1 fuel elements	5-3
5-3.	Core 1 fuel compact initial heavy metal loadings	5-4
5-4.	Core 2 fuel element initial heavy metal loadings	5-5
5-5.	Core 2 fuel compact initial heavy metal loadings	5-6
5-6.	Burnup data for Peach Bottom Cores	5-8
5-7.	Core 1 summary of postirradiation uranium loadings per element by fuel package type	5-9
5-8.	Summary of total postirradiation fuel loadings for 813 elements from Core 1	5-10
5-9.	Postirradiation heavy metal loadings of Core 2 fuel element types, g	5-11
5-10.	Core 2 postirradiation total core heavy metal loadings . . .	5-12
5-11.	Core 2 test element initial heavy metal loadings	5-14
5-12.	Core 2 test element postirradiation heavy metal loadings . .	5-15
5-13.	Peach bottom fuel element fission product inventory	5-16
A-1.	Peach bottom Core 1 spent fuel inventory	A-1
A-2.	Peach bottom Core 2 spent fuel inventory	A-2
A-3.	Peach bottom Core 2 spent test fuel inventory	A-3
A-4.	Peach bottom fuel elements shipped to ORNL	A-4
A-5.	Peach bottom test elements shipped from Philadelphia Electric to GA	A-5
A-6.	Peach bottom test elements shipped from Philadelphia Electric to ORNL	A-6
A-7.	Peach bottom test elements shipped from GA hot cell to ORNL	A-7

1. SUMMARY

This report provides a characterization of the existing Peach Bottom (PB) Unit 1 spent fuel. It includes a complete physical description, an inventory, and the nuclear characteristics of the fuel.

PB Unit 1 was a prototype high-temperature gas-cooled (HTGR) nuclear reactor plant located in Pennsylvania and operated by the Philadelphia Electric Company. The plant was shut down in October 1974 and most of the spent fuel was shipped to the Idaho National Engineering Laboratory (INEL). Some test fuel was shipped to the Oak Ridge National Laboratory (ORNL).

The basic PB fuel element consist of a graphite cylinder 3.5 in. in diameter and 12 ft long. The fueled portion of the element, inside the cylinder, is made up of annular shaped fuel compacts consisting of coated fuel particles bonded with a graphite matrix. The fuel elements are made of graphite and ceramic compounds except for a stainless steel screen located near the bottom of a standard fuel element. Some elements are instrumented with thermocouples.

Two cores were irradiated in the PB reactor. A significant number of fuel element failures in the first core required its premature removal. The second core was operated successfully throughout its design lifetime. All fuel elements from both cores were stored in individually sealed aluminum canisters when they were shipped from the PB site.

Detailed accountability analyses were performed on individual elements to meet the Department of Energy's (DOE) buyback requirements and this information is available both at GA Technologies Inc. (GA) and INEL. Summary data is provided in the report. Fission product inventories and

decay heat rate analyses were not performed in detail and only nominal data was available for this report.

2. INTRODUCTION

GA is performing a characterization and treatment study of Peach Bottom Unit 1 (PB) spent fuel for DOE's Office of Civilian Radioactive Waste Management (OCRWM) under contract with Martin Marietta Energy Systems at ORNL. The objectives of this program are to provide a detailed description of this fuel, determine the requirements for shipping this fuel to a final repository [or Modular Retrievable Storage (MRS)], and identify treatment options which would facilitate its eventual disposal.

This report provides a detailed description and a current inventory of the existing PB Unit 1 spent fuel. Since the PB reactor has been permanently shut down no additional fuel of this type will be generated.

3. DESCRIPTION OF SPENT FUEL

3.1. GENERAL DESCRIPTION

The PB Atomic Power Station utilized a fuel element with an outward appearance of a graphite cylinder 3.5 in. in diameter and 12 ft long. Each of the two cores irradiated in the reactor contained 804 such fuel elements. As discussed in Section 4, the total number of fuel elements irradiated in Peach Bottom exceeded two times 804 because of replacement fuel and test elements. In addition, the core contained 36 control rod guide tubes, and 19 emergency shutdown rod guide tubes, all made of graphite and similar in shape to the fuel elements. All fuel elements are of the same external geometry with a grappling knob at the top for handling.

The basic fuel element, shown in Fig. 3-1, is a solid semihomogeneous type in which graphite served as the moderator, reflector, cladding, fuel matrix and structure. Each fuel element consists of an upper reflector assembly, a fuel bearing middle section, a lower reflector, and an internal fission product trap. The fuel materials, part of the lower reflector and the fission product trap are contained in a sleeve of low-permeability graphite, joining the upper reflector on one end and a bottom connector fitting on the other. A stainless steel screen installed at the bottom of each fission product trap retained any charcoal granules that might have been released from the graphite body of the internal trap during reactor operation. Within the sleeve, the mixture of fissile and fertile materials making up the fuel are contained in annular compacts stacked on cylindrical graphite spines, as shown in Fig. 3-2.

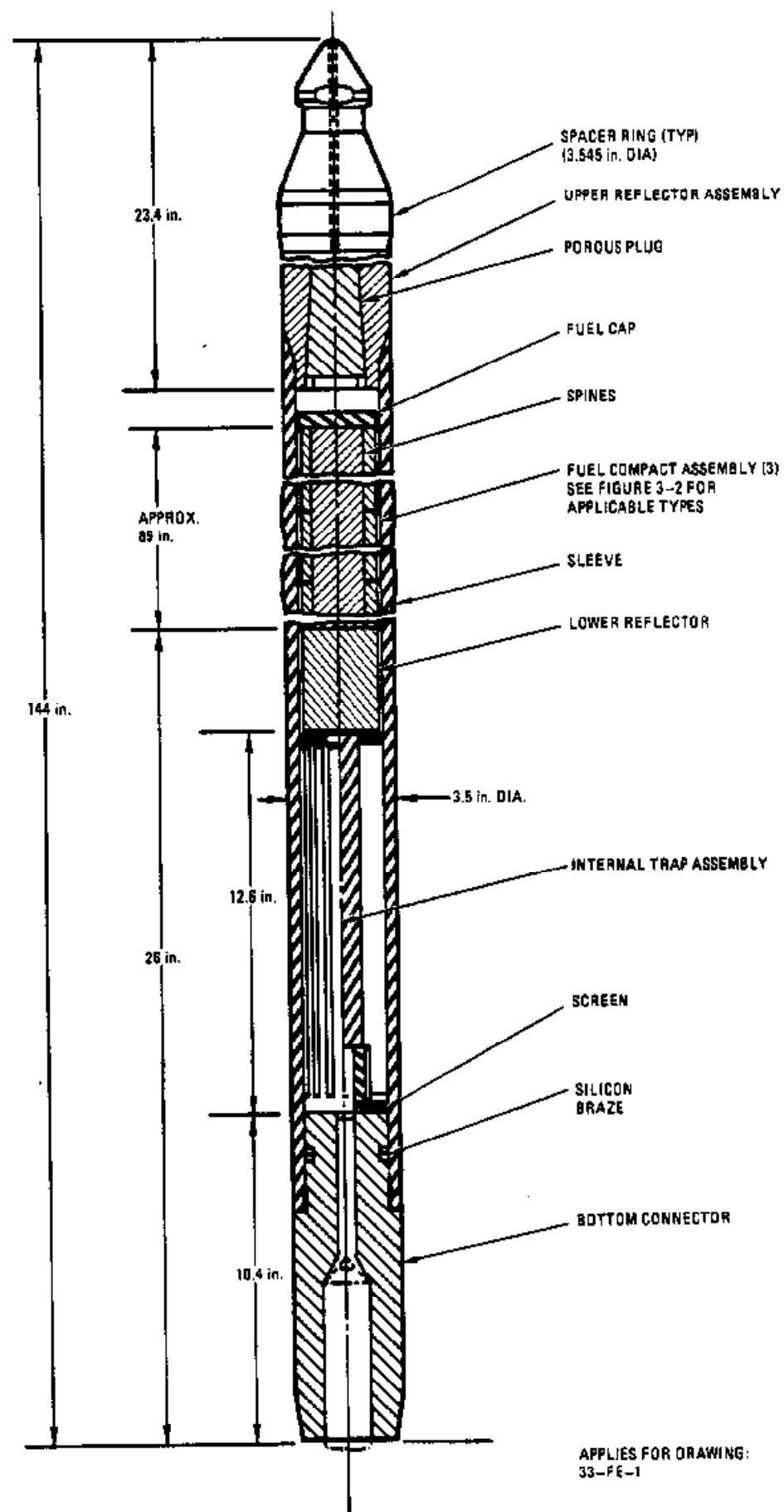


Fig. 3-1. Core 1 fuel element

FUEL TYPE	NUMBER OF ELEMENTS REQUIRED
1	54
2	54
3	14
4	102
	<u>204</u>

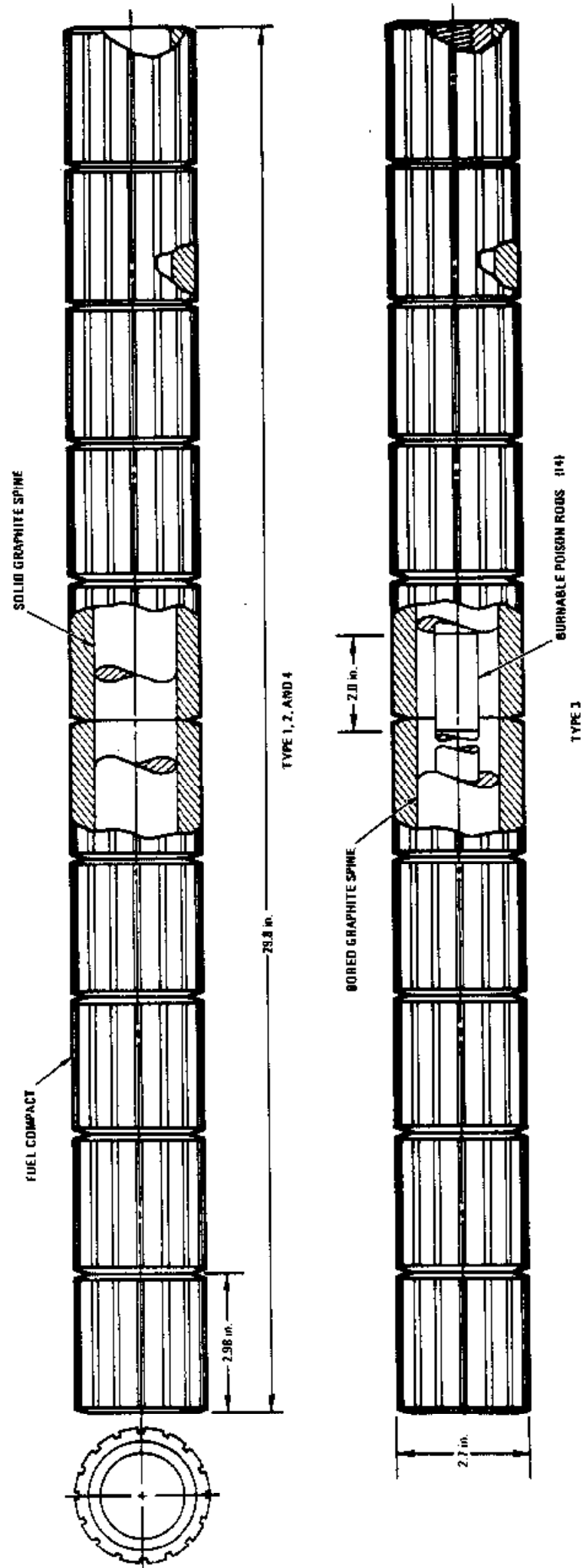


Fig. 3-2. Core 1 fuel compact assembly

The PB reactor core consisted of a number of fuel elements that were instrumented with thermocouples and acoustic thermometers.* Thirty-six such instrumented elements were included in each of the 804 fuel elements required for each core loading. In addition, 33 fuel test elements were irradiated in Core 2 to various exposures to measure thermal, physics, fission product, and materials behavior of commercial HTGR fuel concepts utilizing test assemblies in a representative commercial HTGR neutron spectrum and a helium coolant environment.

3.2. PHYSICAL DESCRIPTION

Three basic fuel element configurations were irradiated in both PB reactor cores; standard fuel elements, as shown in Fig. 3-1, instrumented fuel elements and test elements. Each of these is described below. In addition, the standard and instrumented fuel elements contain four heavy metal loading variations referred to as fuel types I through IV as discussed in Section 5. Note that the proceeding figures indicate GA drawing numbers for the actual blueprints.

3.2.1. Standard Fuel Element - Core 1

Figure 3-1 shows the Core 1 standard fuel element (without the canister) as currently stored at INEL. The elements are in sealed aluminum cans stored in drywells located in the Fermi I Blanket Storage Facility as described in Section 3.6.

The primary components making up the fuel element are a bottom connector, a sleeve, a screen, an internal fission product trap assembly, a lower reflector piece, fuel compacts, spines, burnable poison compacts (in selected elements), a fuel cap, and an upper reflector assembly.

The bottom connector and the sleeve are joined by a silicon braze, and together they form the main barrier against fission product leakage

*Acoustic thermometers were used only in Core 1.

from the fuel element. The fuel cap is a graphite disk which slips loosely into the upper end of the sleeve. All three of these components are made of graphite which have a helium permeability of 3×10^{-3} cm²/s or less, and an effective permeability to gaseous fission products of approximately 10^{-5} cm²/s at reactor conditions.

The screen, internal trap assembly, lower reflector piece, fuel compacts with spines, and the fuel cap are stacked in that order within the sleeve. The weight of these components is supported by the bottom connector. The details of the fuel compacts, spines, and burnable poison compacts, are shown in Fig. 3-2. The lower reflector piece is a 3-in. long graphite cylinder made of reactor grade graphite. The annular fuel compacts are stacked on the cylindrical graphite spine sections. These spine sections are approximately 30 in. long and about 1-3/4 in. in diameter. There are two types of spines, one made of solid graphite, and one with a 0.89 in. diameter hole which was designed to contain burnable poison compacts. The screen is made of 18-8 stainless steel. Its purpose was to retain any charcoal granules that might have been released from the graphite body of the internal trap during operation of the reactor.

The upper reflector assembly is a graphite component which is threaded into the sleeve of the fuel element. This reflector piece engages with the fuel handling machine. A 1/4-in. diameter hole down the centerline of the reflector serves as an inlet channel for purge gas. A porous plug within the upper reflector provides a controlled pressure drop for inflowing purge gas.

The uranium and thorium within the fuel compacts are in the form of carbides uniformly dispersed as coated particles in the graphite matrix. The fuel compacts were fabricated by a warm-press and sintering operation. The compact sintering temperature was 1800°C.

The fuel compacts consisted of carbides of uranium [enriched to 93.15% U-235 at beginning of life (BOL)] and thorium, uniformly dispersed

as coated particles in a graphite matrix. The total carbon within the carbide substrates was between 11% and 16% by weight at BOL for Core 1. The pyrolytic carbon coated particles are between 210 and 595 microns in diameter, with coating thicknesses of 55 ± 10 microns for Core 1. The size distribution of the particles was selected such that the volume fraction of the coated particles did not exceed 30% of the total compact volume.

Burnable poison compacts, cylindrical in shape, were placed in hollow spines of some of the fuel elements. Each compact contains 0.436 ± 0.030 g of natural boron in the form of zirconium diboride pressed into a graphite matrix. The maximum particle size of the zirconium diboride is 100 microns.

3.2.2. Instrumented Fuel Element - Core 1

Thirty-six fuel elements were instrumented for temperature measurement in various locations of the core. Each of these elements was instrumented with two thermocouples, and eight also contained acoustic thermometers. An acoustic thermometer is an instrument which utilizes the proportionality between resonance frequency of a transmitted sound wave and the temperature of helium gas in a cavity within the fuel element to determine the temperature. Table 3-1 lists the number of instrumented fuel elements in each of the fuel loading types 1 through 4. Figure 3-3 is a schematic of a typical Core 1 instrumented fuel element (without the canister) as stored at INEL.

The instrumented fuel elements are very similar to the standard fuel elements. The differences involve the bottom connector and certain internal components which are slightly modified to allow passage of the thermocouple leads. These leads extend to different axial locations in the element as listed in Table 3-1.

TABLE 3-1
USES OF THERMOCOUPLES IN INSTRUMENTED FUEL ELEMENTS

No. of Instrumented Fuel Elements	Fuel Loading Type	Use of Thermocouples	Reference Drawing No.
8	1 and 2	Spine and sleeve temperature. Also acoustic thermometer at center, hot spot height	33-FE-10
3	1	Axial profile of center of core - spine temperature	33-FE-20
5	1, 2, 3, and 4	Radial profile - spine plus internal trap inlet temperature	33-FE-20
7	1, 2, and 3	Radial profile - both thermo- couples for spine temperature	33-FE-20
3	2	Both thermocouples for spine temperature	33-FE-20
2	4	Low U loading - both thermo- couples for spine temperature	33-FE-20
2	1 and 2	Internal trap inlet and out- let temperature	33-FE-40
2	2 and 4	Standoff and bottom reflector temperature	33-FE-30
3	2	Axial profile at edge of core - spine temperature	33-FE-20
1	3	Boron loaded - both thermo- couples for spine temperature	33-FE-20

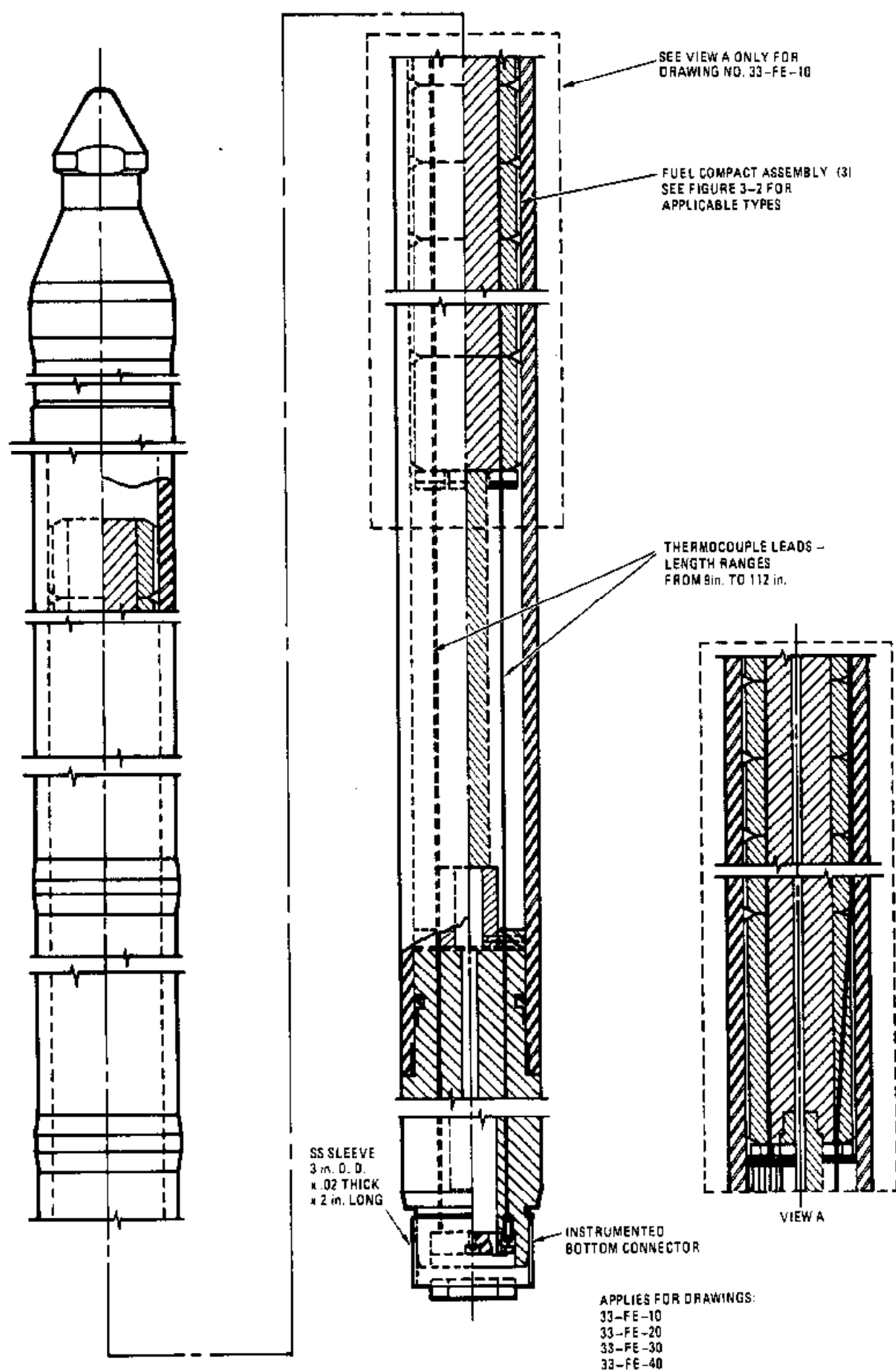


Fig. 3-3. Core 1 instrumented fuel element

3.2.3. Standard Fuel Element - Core 2

Figure 3-4 shows the Core 2 standard element as currently stored at INEL. The elements are stored in canisters located in the Irradiated Fuel Storage Facility as described in Section 3.6.

The Core 2 standard fuel elements are essentially the same as the Core 1 elements. The only design difference is in the coated particles and the external appearance of fuel compacts. The coated particles in Core 1 used monolithic laminar pyrolytic coatings whereas the Core 2 coated particles consisted of an inner, low density, pyrolytic carbon coating surrounded by an outer isotropic pyrolytic carbon coating. The coated particles are between 340 and 630 microns in diameter with a total coating thickness of 90 to 130 microns. The Core 2 compacts do not have the axial grooves included in the Core 1 compacts, as shown in Fig. 3-5. Core 2 compacts have slots on the ends which were not included in the Core 1 compacts.

In the as-stored configuration, the Core 2 element differs from the Core 1 element in that the top 18 in. of the upper reflector was cut off at INEL prior to storage in the facility. This is shown as Fig. 3-4. Note that the bottom connector for the element placed in the B1610 position (within the core), is somewhat different from a standard fuel element.

3.2.4. Instrumented Fuel Element - Core 2

Core 2 shared its instrumented core locations with instrumented fuel elements and instrumented test elements. The instrumented fuel elements for Core 2 are of the same design as the Core 1 with the exceptions noted in the previous sections concerning fuel compact design and the cut-off upper reflector. Figure 3-6 shows a typical Core 2 instrumented fuel element as stored at INEL.

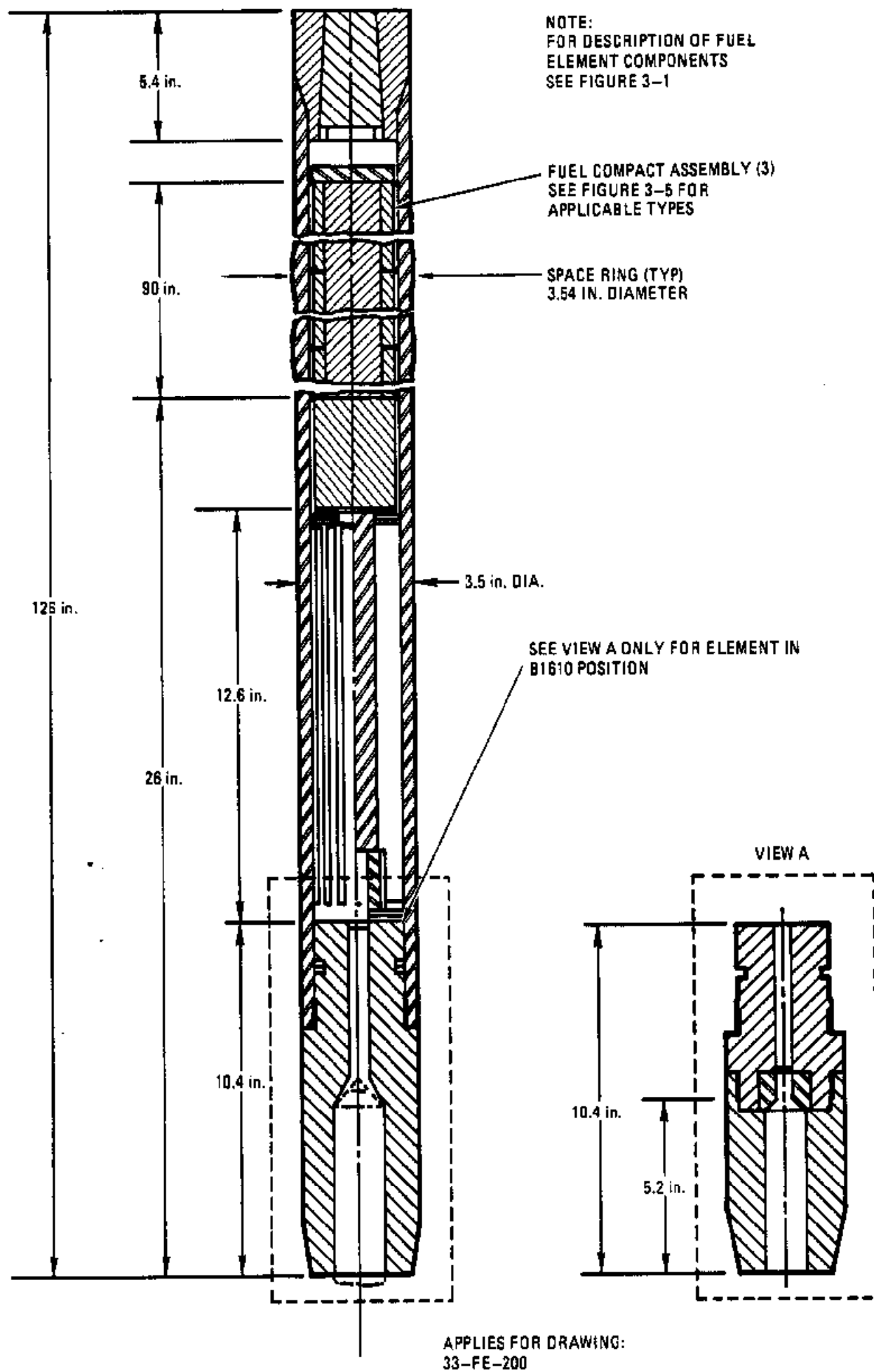


Fig. 3-4. Core 2 fuel element

FUEL TYPE	NUMBER OF ELEMENTS REQUIRED
1	53
2	556
3	75
4	182
	<u>766</u>

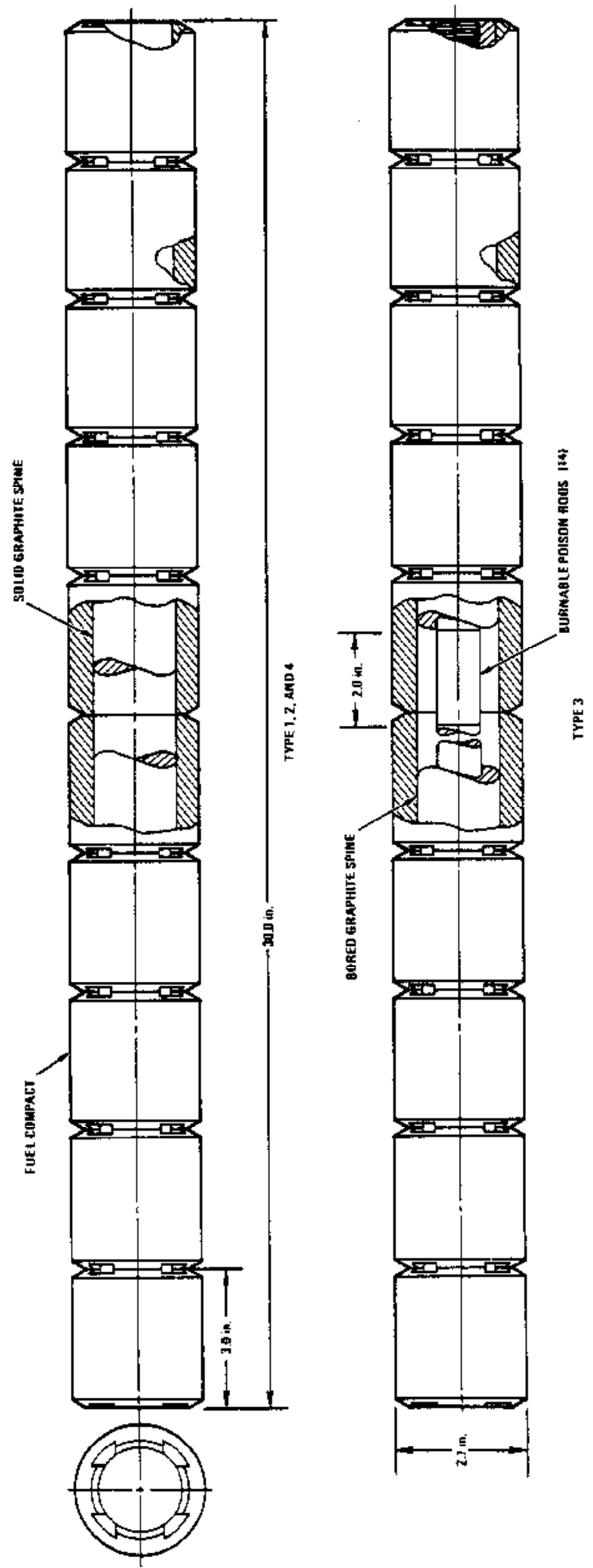


Fig. 3-5. Core 2 fuel compact assembly

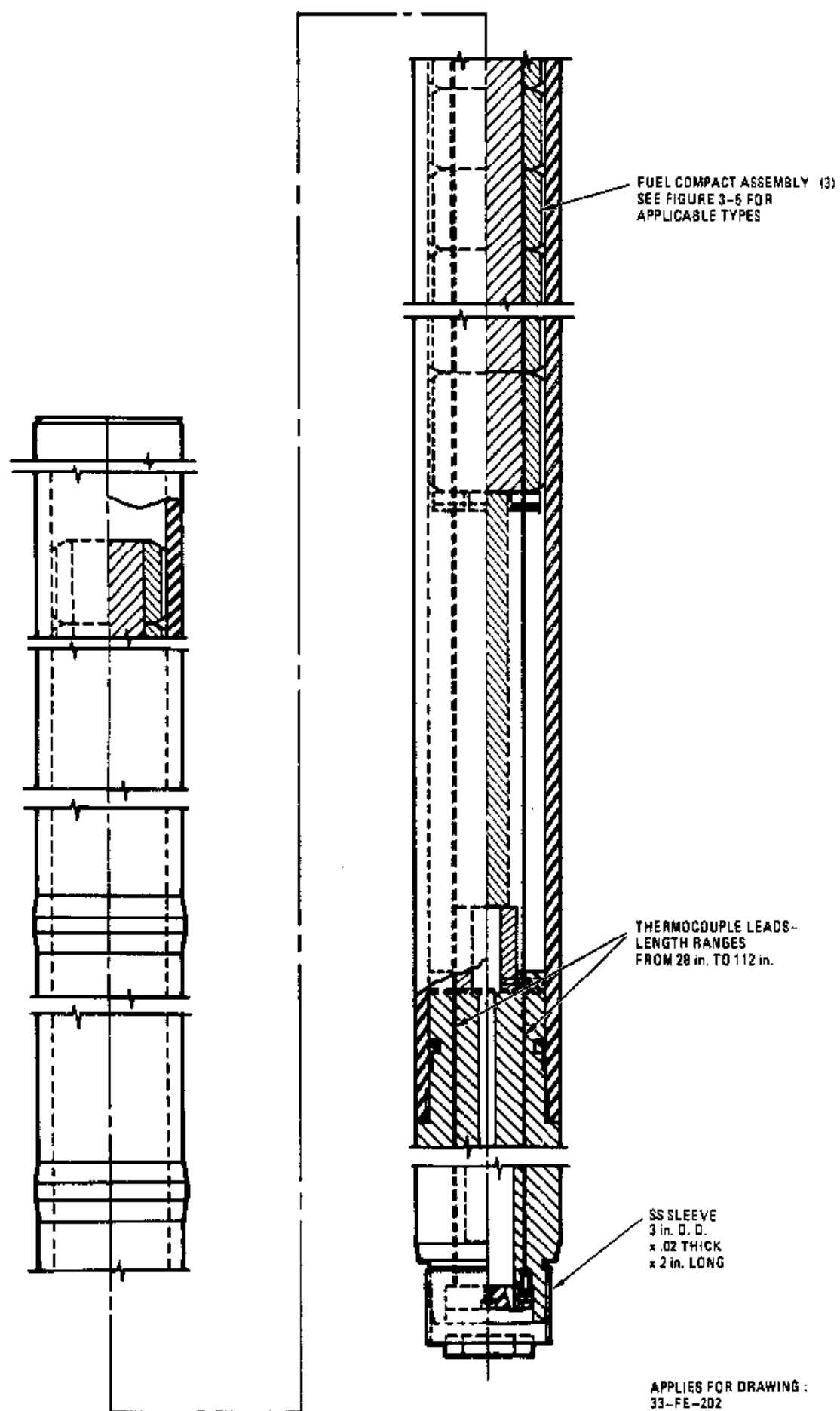


Fig. 3-6. Core 2 instrumented fuel element

3.2.5. Test Fuel Elements

Since the PB Unit 1 reactor offered unique capabilities as a test facility for HTGR type fuels, test assemblies were tested in the core to evaluate interactions of fuel particles, fuel beds and graphite structures. Test elements were included in both Core 1 and Core 2. Figure 3-7 shows two configurations currently in storage at INEL and ORNL.

Two test elements of the proof test element (PTE) type were irradiated in Core 1. The first, PTE-1, did not perform correctly, and was removed, and shipped to INEL for storage. The second, PTE-2, remained in the core for further irradiation with Core 2.

An additional 32 test elements were constructed and irradiated in Core 2. These were manufactured in three classes of test elements - fuel test elements (FTEs)/fuel bed test elements (FBTEs), PTEs, and fuel pin test elements (FPTEs). Of the total 33 elements, 30 were of the FTE/FBTE design, one was of the PTE design, and two of the FPTE design. The FPTEs were irradiated for UKAEA and were returned to the United Kingdom following their irradiation in the PB core and subsequent postirradiation examination (PIE) in the United States.

Table 3-2 lists the 33 test elements, along with important parameters of each one of these elements.

The PTE test elements are hexagonal in shape as shown in Fig. 3-7 and do not utilize graphite sleeves. The element is made up of four separate fuel sections containing fuel holes and coolant holes. These four sections along with a top reflector, bottom reflector and bottom connector were threaded together to form an assembly approximately 3.5 in. across flats and 140 in. long. The top and bottom reflectors were specially designed to allow a special handling tool and coolant flow inlets and exits. The element was instrumented with two thermocouples. A description of the PTEs is given in Ref. 1.

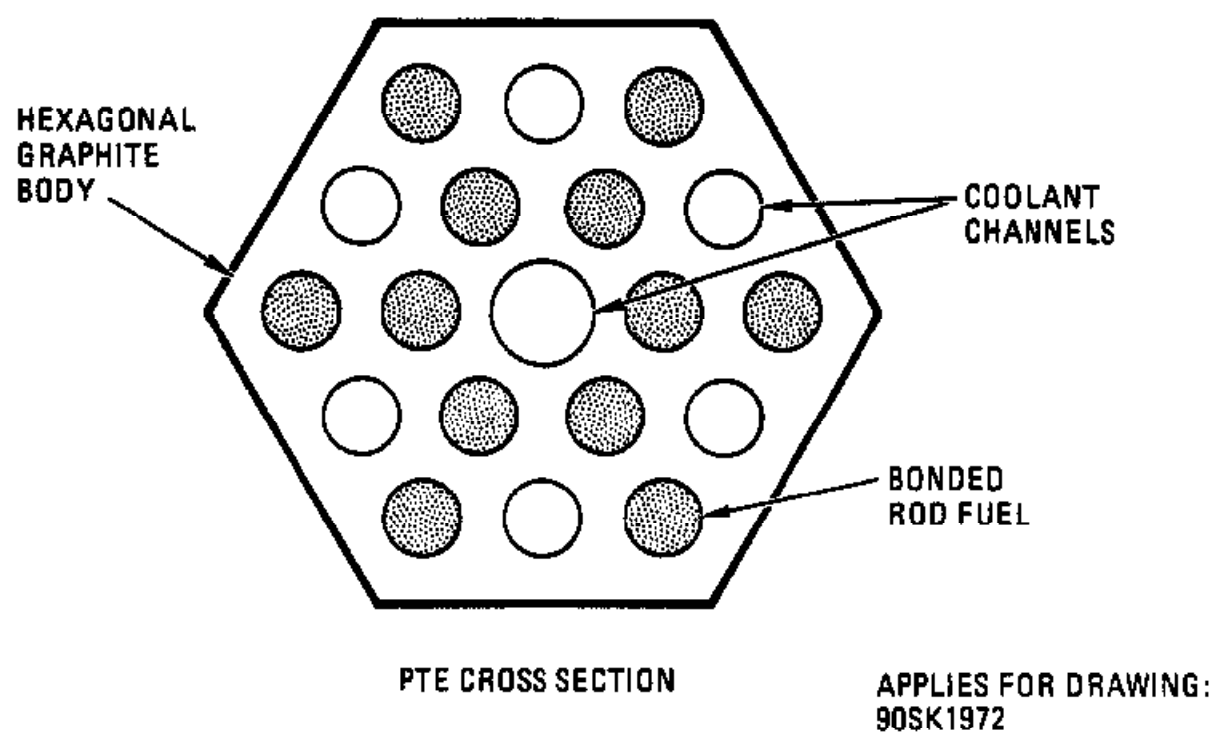
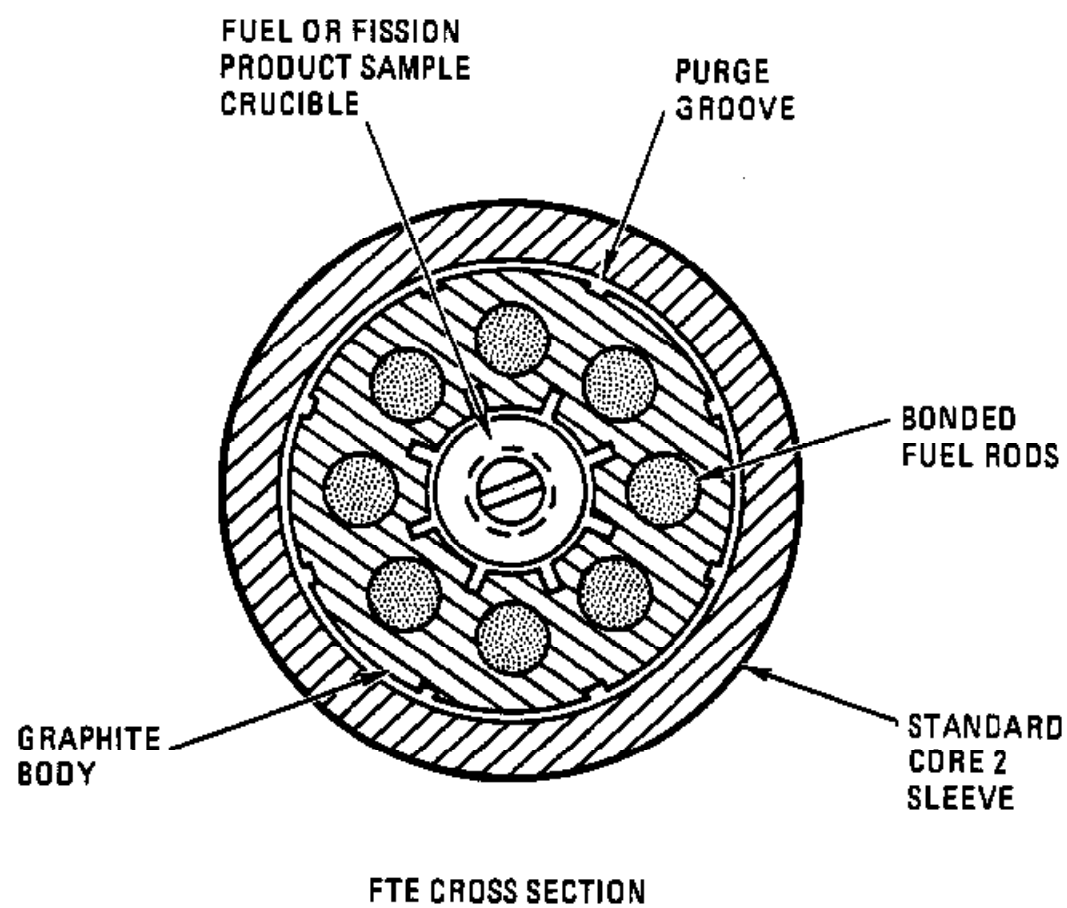


Fig. 3-7. Cross sections of test element classes

TABLE 3-2
PEACH BOTTOM TEST ELEMENTS IRRADIATED IN CORE 2

Element	Phase(a)	Thermocouples	Fuel Bed	Description/Fuel Type
PTE-2(b)	1	Yes	Rods(c)	Proof test element for PSV - rods
FBTE-1	1	Yes	Rods	Fuel bed test element for LHTGRs - bonded rods
FBTE-2	1	Yes	Rods	Fuel bed test element for LHTGRs - bonded rods
FBTE-3	1	Yes	Rods	Fuel bed test element for LHTGRs - bonded rods
FBTE-4	1	Yes	Rods	Fuel bed test element for LHTGRs - bonded rods
FBTE-5	1	No	Blended(d)	Fuel bed test element for LHTGRs - blended bed
FBTE-6	1	Yes	Blended	Fuel bed test element for LHTGRs - blended bed
FTE-1	1	Yes	Blended	Fuel test element for LHTGRs - blended bed
FTE-2	1	Yes	Blended	Fuel test element for LHTGRs - blended bed
FTE-5	1	Yes	Rods	Fuel test element for LHTGRs - bonded rods
RTE-2	1	No	Mixed	Recycle test element for ORNL - 1/2 beds, 1/2 rods
RTE-4	1	No	Mixed	Recycle test element for ORNL - 1/2 beds, 1/2 rods
RTE-5	1	No	Rods	Recycle test element for ORNL - bonded rods
RTE-6	1	No	Rods	Recycle test element for ORNL - bonded rods
RTE-7	1	No	Rods	Recycle test element for ORNL - bonded rods
RTE-8	1	NO	Rods	Recycle test element for ORNL - 1/6 beds, 5/6 rods
FPTE-1	1	Yes	Compacts	Fuel pin test element for UKAEA - fuel pins
FTE-3	2	Yes	Rods	Fuel test element for LHTGRs
FTE-4	2	?	Rods	Fuel test element for LHTGRs
FTE-6	2	Yes	Rods	Fuel test element for LHTGRs

TABLE 3-2 (Continued)

Element	Phase(a)	Thermocouples	Fuel Bed	Description/Fuel Type
FTE-7	2	Yes	Rods	Fuel test element for LHTGRs
FTE-8	2	Yes	Rods	Fuel test element for LHTGRs
FTE-9	2	Yes	Rods	Fuel test element for LHTGRs
FTE-10	2	Yes	Rods	Proof test element for FSV
FTE-11	2	No	Rods	Recycle test element for ORNL
FTE-12	2	Yes	Rods	Fuel test element for LHTGRs
FPTE-3	2	Yes	Compacts	Fuel pin test element for UKAEA
FTE-13	3	Yes	Rods	Plutonium fuel test
FTE-14	3	Yes	Rods	Large HTGR fuel test
FTE-15	3	Yes	Rods	Large HTGR fuel test
FTE-16	3	Yes	Rods	FSV fuel proof test
FTE-17	3	Yes	Rods	FSV fuel proof test
FTE-18	3	Yes	Monolithic	HOEG/KFA molded fuel body test

(a) Phase 1 loaded at 0 EFPD of Core 2, Phase 2 loaded at 252 EFPD of Core 2, and Phase 3 loaded at 385 of Core 2.

(b) PTE-2 was irradiated 152 EFPD in Core 1, prior to irradiation in Core 2.

(c) A fuel rod, as used here, is a close-packed assembly of coated fuel particles bonded together with a carbonaceous matrix.

(d) A blended bed, as used here, is a close-packed assembly of unbonded, coated fuel particles.

The remaining test elements in storage are similar in external appearance to the standard and instrumented fuel elements. The fueled portion of the elements contain six fuel bodies* as shown in Figs. 3-8 and 3-9. These fuel bodies have eight fuel holes surrounding a central hole. The fuel holes contain either fuel rods or loose fuel particles. Descriptions of the test elements are included in Refs. 2 through 14.

3.3. MATERIALS (REFS. 15 AND 16)

3.3.1. Nonfuel Components

The nonfuel components of the PB spent fuel elements are shown in Figs. 3-1 and 3-3 and are listed below with their associated materials:

<u>Component</u>	<u>Material</u>
Upper reflector	Graphite
Porous plug	Graphite
Fuel cap	Graphite
Sleeve	Graphite
Lower reflector	Graphite
Internal trap	Graphite
Screen	Stainless steel
Brazing ring	Silicon
Bottom connector	Graphite
Instrumented bottom connector**	Graphite, stainless steel, Inconel
Thermocouples**	Inconel sheath, Tungsten-rhenium, Chromel-alumal Nb-1% Zr sheath

*Some test elements contain three fuel bodies.

**Instrumented elements only.

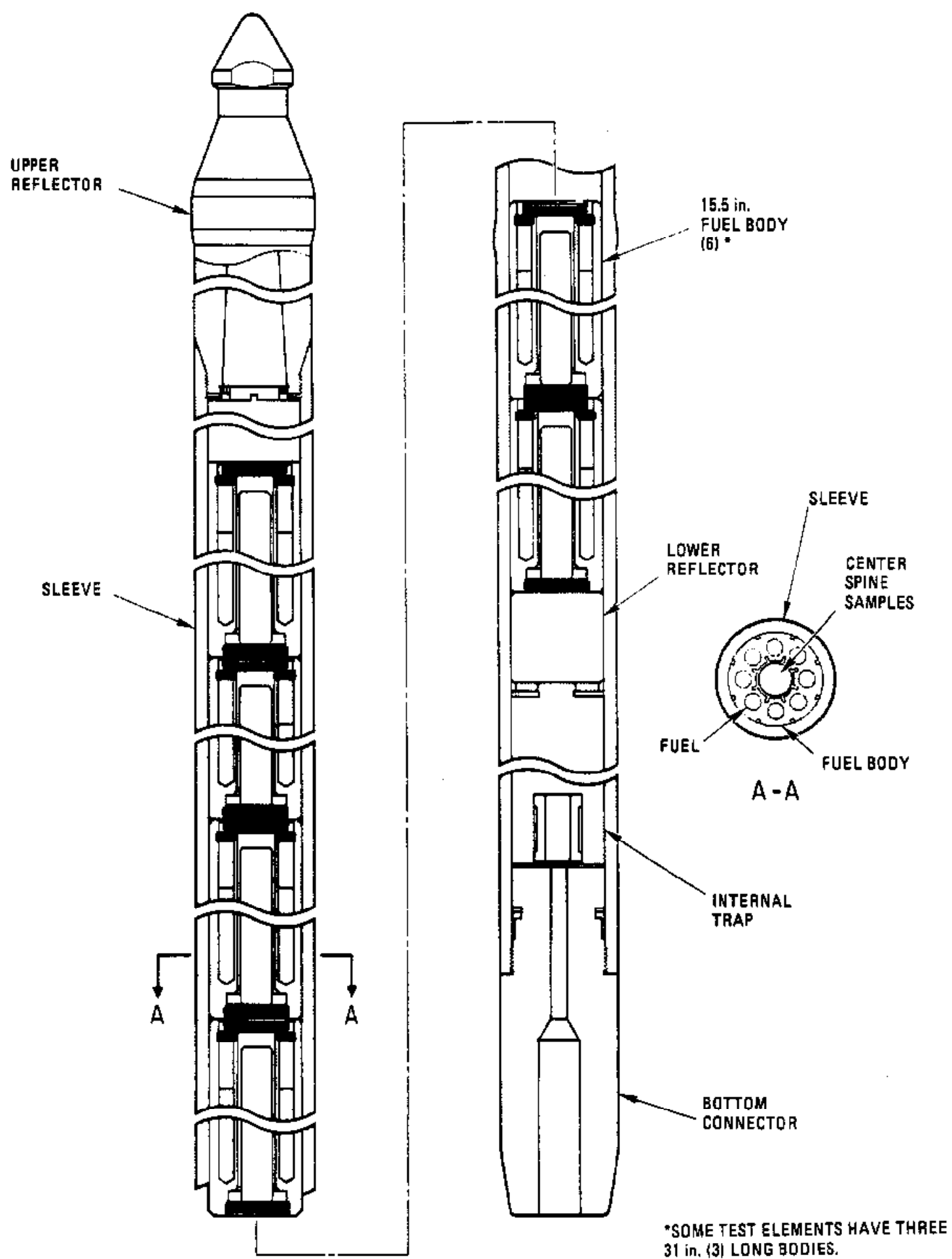
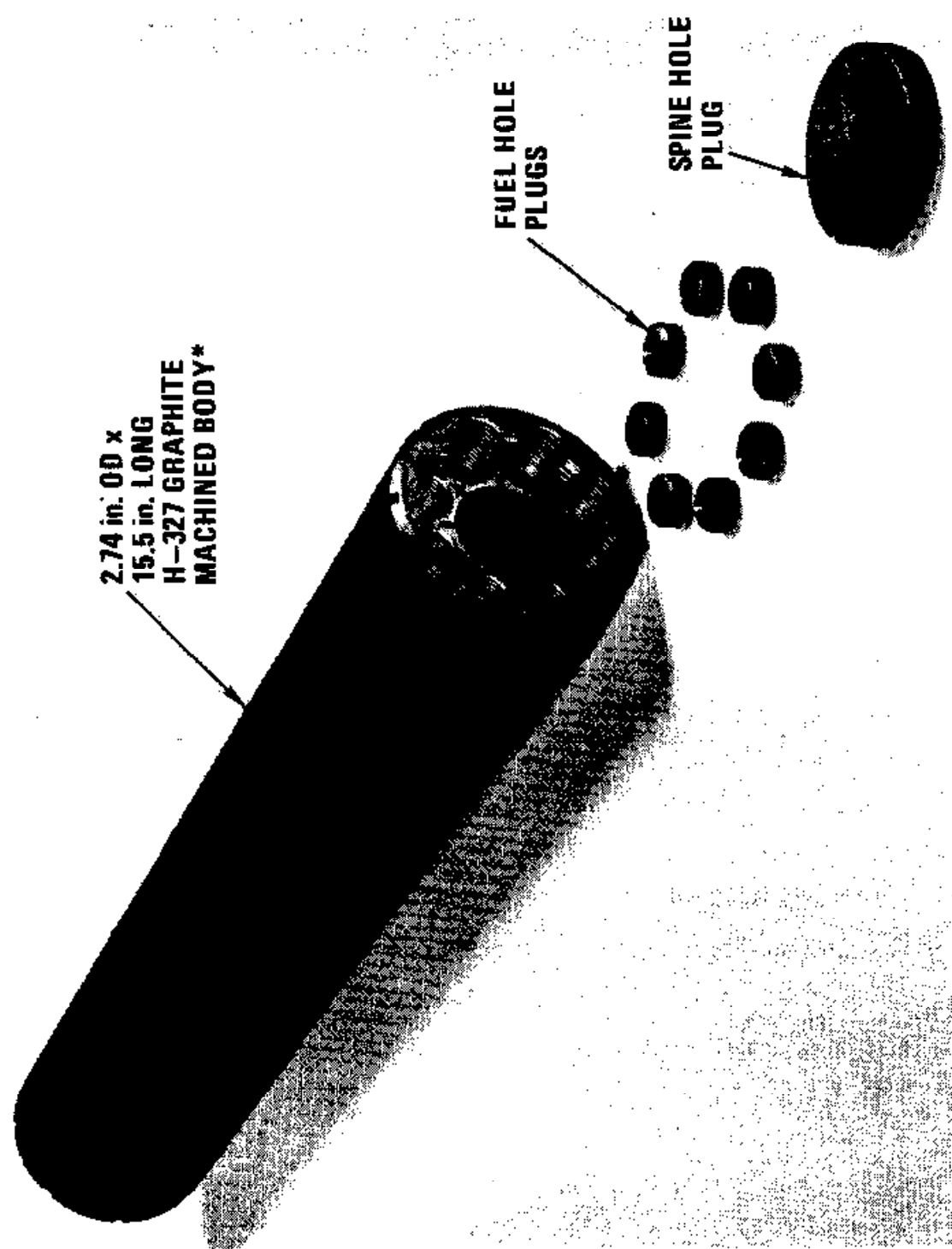


Fig. 3-8. Typical fuel test element assembly



***SOME TEST ELEMENTS HAVE THREE 31 in. LONG BODIES.**

Fig. 3-9. Typical fuel test element fuel body

Table 3-3 lists the composite chemical purity for various components in a Core 1 fuel element.

3.3.2. Fuel Assemblies

The fueled portion of the PB fuel elements was made up of three fuel compact assemblies consisting of the following components:

<u>Component</u>	<u>Material</u>
Fuel compacts	Pyrolytic carbon coated UC ₂ /ThC ₂ particles in graphite matrix
Solid or bored spines	Graphite
Burnable poison compacts	ZrB ₂ in graphite matrix

The impurity elements in the spines for a Core 1 fuel element did not exceed:

Ash	243.0 ppm
Boron	0.4 ppm
Iron	1.7 ppm
Molybdenum	<1.0 ppm
Sulfur	11.0 ppm
Titanium	32.0 ppm
Vanadium	2.4 ppm

TABLE 3-3
CORE 1 FUEL ELEMENT COMPOSITE CHEMICAL PURITY (ppm)

Elements	Upper Reflector	Sleeve and Bottom Connector	Lower Reflector and Trap Assembly
Ash	32.0	--	14.7
Boron	0.7	<5.0	0.1
Iron	63.5	<30.0	1.0
Molybdenum	7.5	<8.0	<1.0
Sulfur	15.0	--	10.2
Titanium	20.5	<20.0	<1.0
Vanadium	3.5	<6.0	0.4

The fueled portion of the PB test elements was made up of three or six fuel bodies consisting of the following components:*

<u>Component</u>	<u>Material</u>
Body	Graphite
Fuel rods	UC ₂ /ThC ₂ particles bonded together by a carbonaceous matrix
Spine samples	Fission product release samples and/or metallic diffusion samples

The spine samples for the fission product release samples consisted of coated particles loaded into inner graphite crucibles, which in turn were placed inside larger graphite crucibles.** Each inner crucible was surrounded by coke and the lid was then screwed on the larger crucible.

The spine samples for the metallic diffusion samples consisted of highly enriched or tagged isotopes of Cs, Cr, Sm, and Ba. They were sorbed onto matrix material and converted into carbide before loading into graphite crucibles.

3.4. WEIGHTS

3.4.1. Assembly Weights

The weights of the different styles of fuel elements are listed below:

	<u>Approximately</u>
Standard fuel element	41 kg
Instrumented fuel element	41 kg

*Represents the basic composition for most of the test elements.

**Some of the larger graphite crucibles were made of niobium. These niobium crucibles were electron-beam welded shut after the inner crucibles had been loaded inside.

	<u>Approximately</u>
Fuel test element (PTE designs)	45 kg
Fuel test element (others)	41 kg
Core 2 cut-off fuel element	38 kg
Core 2 cut-off instrumented fuel element	38 kg
Core 1 fuel element with storage canister	68 kg
Storage basket with Core 1 fuel	1642 kg

3.4.2. Component Weights

	<u>Approximately</u>
Upper reflector	6 kg
Sleeve	13 kg
Lower reflector	0.6 kg
Internal trap	2 kg
Bottom connector	3 kg
Fuel compact assembly	5 kg
Fuel compact	0.4 kg

3.4.3. Material Weights

Each fuel element contains the following quantities of materials:

<u>Material</u>	<u>Approximately</u>
Carbon	33 kg
Stainless steel	5 g
Uranium	(Section 5)
Thorium	(Section 5)
Rhodium	0-31 g
Boron	0-15 g
Silicon	15 g

3.5. POSTIRRADIATION CONDITION OF SPENT FUEL

The condition of Core 1 and Core 2 is sufficiently different to warrant a discussion of each.

3.5.1. Core 1

Core 1 operated approximately half of its design lifetime accumulating 451.5 equivalent full power days (EFPD). Fuel failures necessitated replacement of the core with Core 2.

The Core 1 fuel contained fuel particles coated with a single layer of pyrolytic graphite. Fast-neutron-induced dimensional changes and damage due to fission product recoils resulted in cracking and distortion of the coatings on the fuel particles. The broken coatings, in the process of curling and changing dimensions, caused the compacts to distort and swell. The radial expansion produced in the compacts caused them to bind against the graphite sleeve, causing some sleeves to fracture. A total of 90 elements in Core 1 developed cracked sleeves (Ref. 17). Two elements were broken during core removal.

The fuel in the balance of the core remained intact and was removed and packaged for disposal. It can be assumed that some of the fuel particles failed and some of the compacts experienced swelling in this fuel. Several Core 1 elements were examined and the results were reported in a series of reports given in Ref. 17. Based on these examinations it is expected that the compacts can be removed from the graphite sleeves if this becomes a viable treatment option.

3.5.2. Core 2

Core 2 operated close to its full design lifetime of 900 EFPDs. The design of a new coated fuel particle solved the problem experienced in Core 1 and all elements were in good condition after removal from the reactor.

In order to store the Core 2 fuel in the Irradiated Fuel Storage Facility at the INEL Idaho Chemical Processing Plant (ICPP) it was necessary to cut off 18 in. from the top of each Core 2 fuel element. This is shown in Figs. 3-4 and 3-6. This operation was completed at INEL with no damage to the balance of the fuel element.

Postirradiation examinations were performed on several Core 2 regular fuel elements. In addition to the reports listed in Ref. 17, Refs. 18 through 23 provide data on the condition of this fuel.

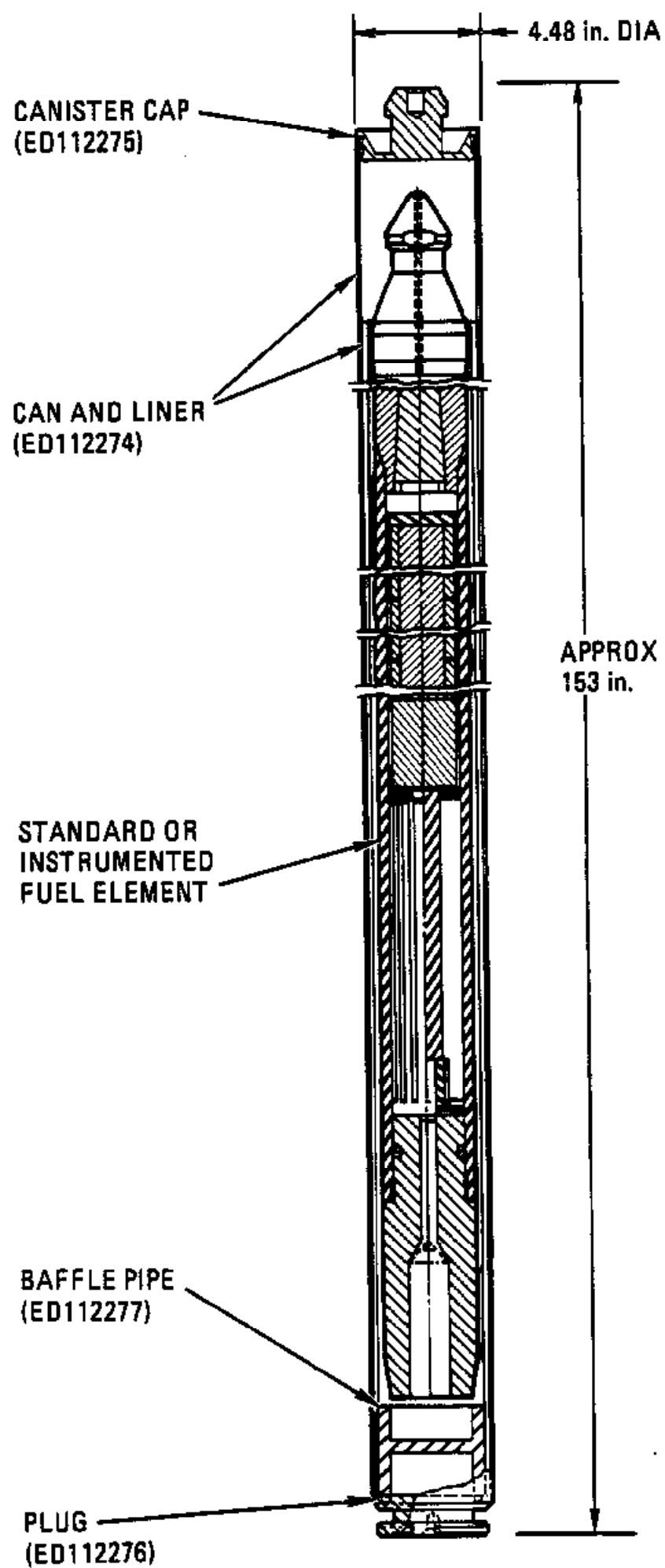
3.6. PACKAGING

3.6.1. Core 1

Core 1 is currently stored in open-field drywells at the ICPP Fermi I Blanket Storage Facility at INEL. Each individual fuel element was placed in sealed aluminum canisters with a stainless steel liner at PB after removal from the reactor. The failed fuel was removed from the core with a stainless steel failed fuel element tool and both the tool and the element were placed in a sealed canister. Figures 3-10 and 3-11 describes the canisters with and without the removal tool. The loaded canisters weigh about 150 lb. Figure 3-12 shows a salvage canister surrounding a leaking canister. The part numbers given on these figures are identification numbers defined by Philadelphia Electric in Ref. 24.

The canisters of fuel were shipped to INEL in the PB fuel shipping cask. The elements were positioned in the cask with a basket assembly. At INEL, the entire basket loaded with canisters was lowered into the drywell. A loaded basket assembly weighs 3620 lb.

Removal and canning of the failed Core 1 fuel resulted in a number of package types. These are given in Table 3-4 (Ref. 24).



FUEL PACKAGE TYPE	NUMBER OF PACKAGES
1	528
9	71
14	98
17	1
18	18
20	3
21	4
	<hr/> 723

Fig. 3-10. Core 1 non-failed fuel element in storage canister

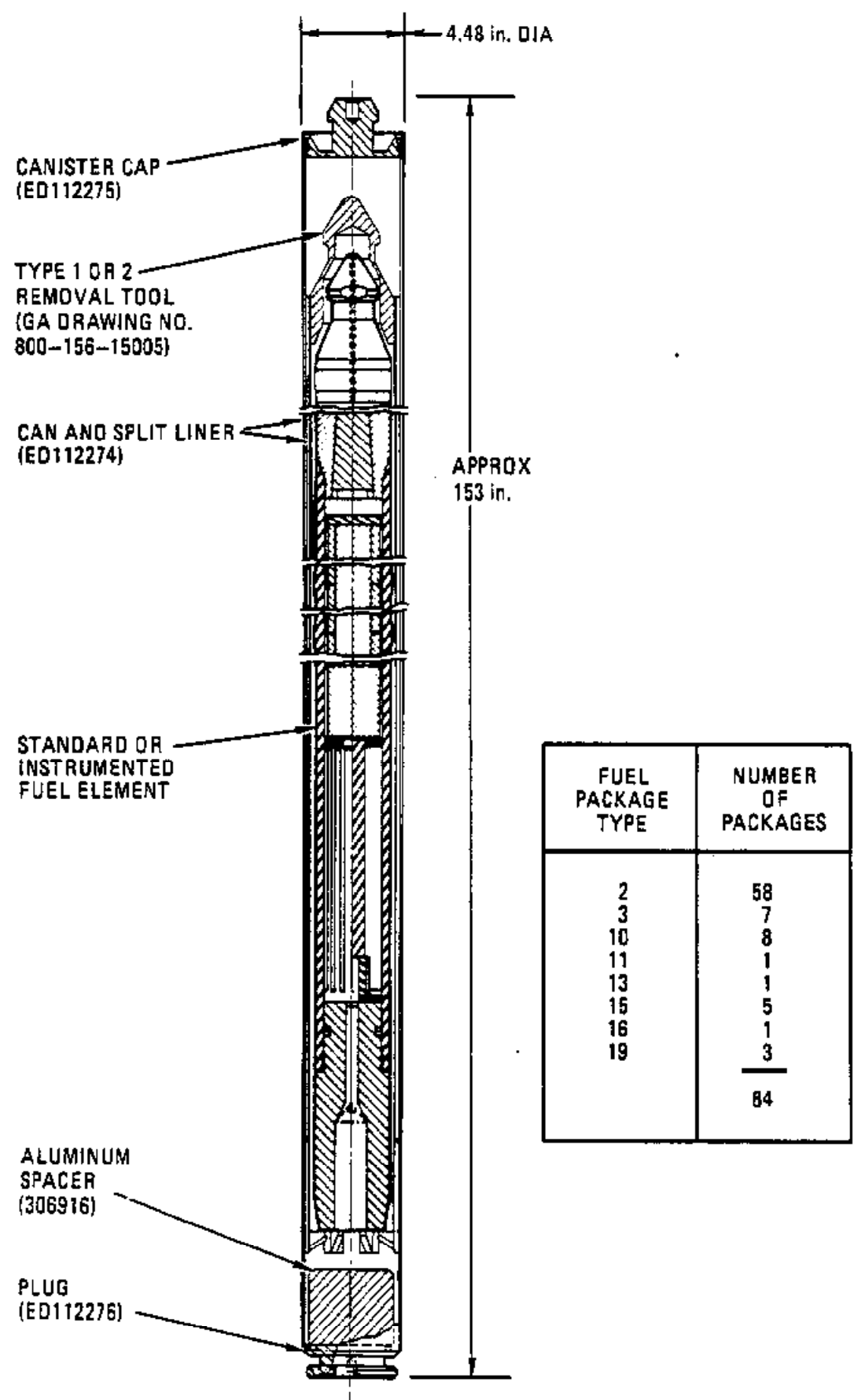
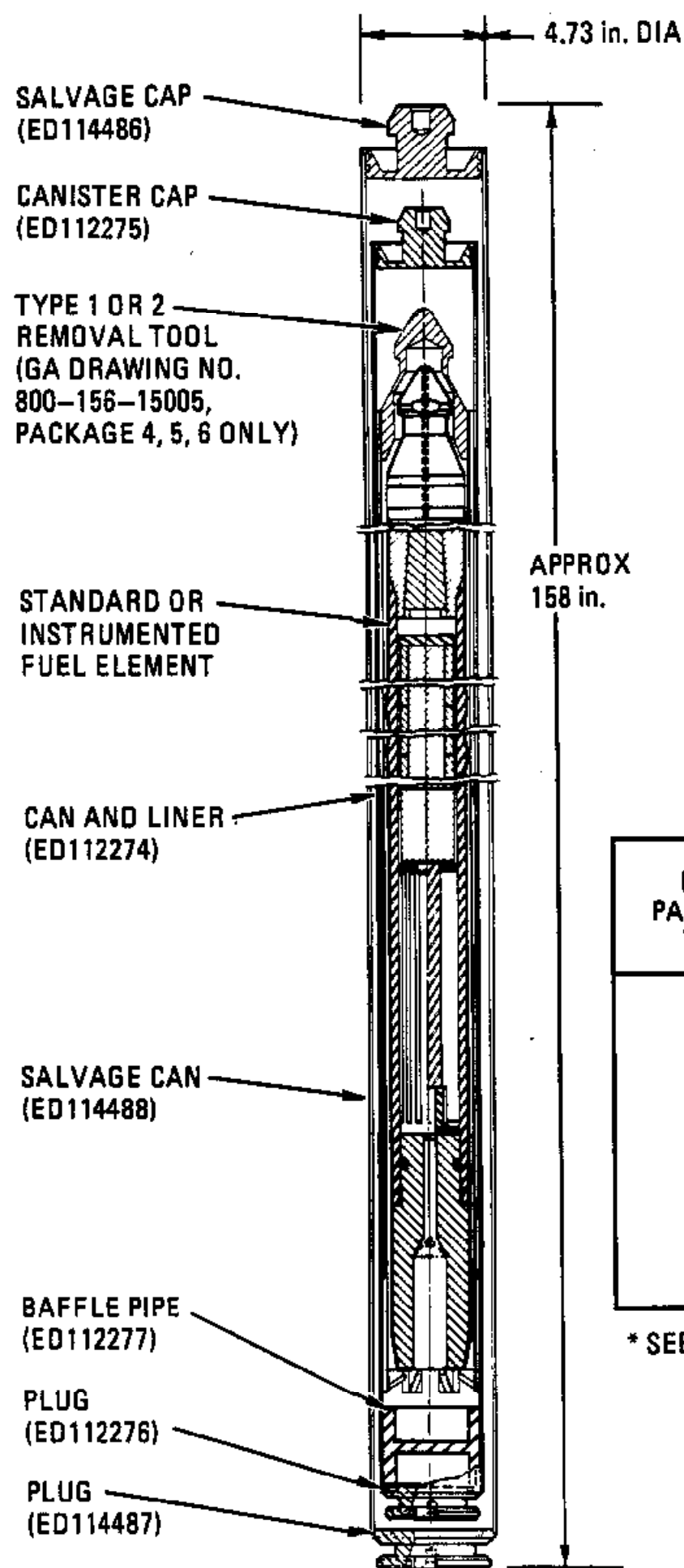


Fig. 3-11. Core 1 fuel element in storage canister with removal tool



FUEL PACKAGE TYPE *	NUMBER OF PACKAGES
4	1
5	1
6	1
7	1
8	1
12	1
	<hr/>
	6

* SEE TABLE 3-3

Fig. 3-12. Core 1 failed fuel element in storage canister with removal tool in salvage canister

TABLE 3-4
CORE 1 SPENT FUEL PACKAGE TYPES

Fuel Package Type	No. of Elements	Description
1	528	Type I or II fuel element, regular can and liner.
2	58	Type I or II fuel element, failed sleeve, normal can, split liner, spacer, type 2 removal tool.
3	7	Fuel assembly type 2 with a type 1 removal tool.
4	1	Type II fuel element (No. 263) broken and stored in 2 containers. Upper portion of element with 21 compacts is in a salvage can with unmarked salvage cap with partial type 2 removal tool, special spacer, component canister, 4.25 in. spacer and 50 lb of steel shot. Lower portion of element with 9 compacts is in a regular canister (cap No. 120) with a 3.25 in. spacer and a special GGA pulling tool.
5	1	Type II fuel element (No. 451), failed sleeve, normal can, split liner, spacer, type 1 removal tool. Due to leaking canister, recanned in salvage canister with special vented cap, unmarked.
6	1	Type II fuel element (No. 576), failed sleeve, type 2 removal tool, component canister and spacer in salvage canister, cap No. 8.
7	1	Type 2 fuel assembly in a salvage canister (cap No. 851, fuel element No. 731).
8	1	Type 2 fuel element (No. 848) less upper reflector canned in salvage canister (component canister and 4 in. spacer inside). Salvage cap is unmarked.
9	71	Type 3 fuel element, regular can and liner.
10	8	Fuel assembly type 2 with a type 3 fuel element.
11	1	Fuel assembly type 10 with a hollowed out cap (No. 90) due to a removal tool positioned too high (element No. 126).

TABLE 3-4 (Continued)

Fuel Package Type	No. of Elements	Description
12	1	Fuel assembly type 10 recanned in salvage canister with cap C5 (element No. 306).
13	1	Type 10 fuel assembly (element No. 870) in can No. 14 (cap unmarked) with type 1 removal tool.
14	98	Type 4 fuel element, regular can and liner.
15	5	Type 2 fuel assembly with acoustic thermometer installed.
16	1	Type 15 fuel assembly (fuel element No. 807) in can 01, cap unmarked, with a type 1 removal tool.
17	1	Type 1 fuel assembly (fuel element No. 808 and cap No. 252R) with acoustic thermometer installed.
18	18	Type 1 fuel assembly with thermocouple installed.
19	3	Type 2 fuel assembly (element No. 848) with thermocouple installed.
20	3	Type 9 fuel assembly with thermocouple installed.
21	4	Type 14 fuel assembly with thermocouple installed.

3.6.2. Core 2

The Core 2 spent fuel was packaged for shipment using the same type of canister used for Core 1. However, the Core 2 fuel was placed in the Irradiated Fuel Storage Facility at INEL. This required removal of the fuel from the canister and cutting of the top reflector to store the element in the 11-ft-long storage canister. Therefore, the resulting element length is approximately 10 ft 6 in. Each canister, shown in Fig. 3-13 (Ref. 25), contains 12 PB elements.

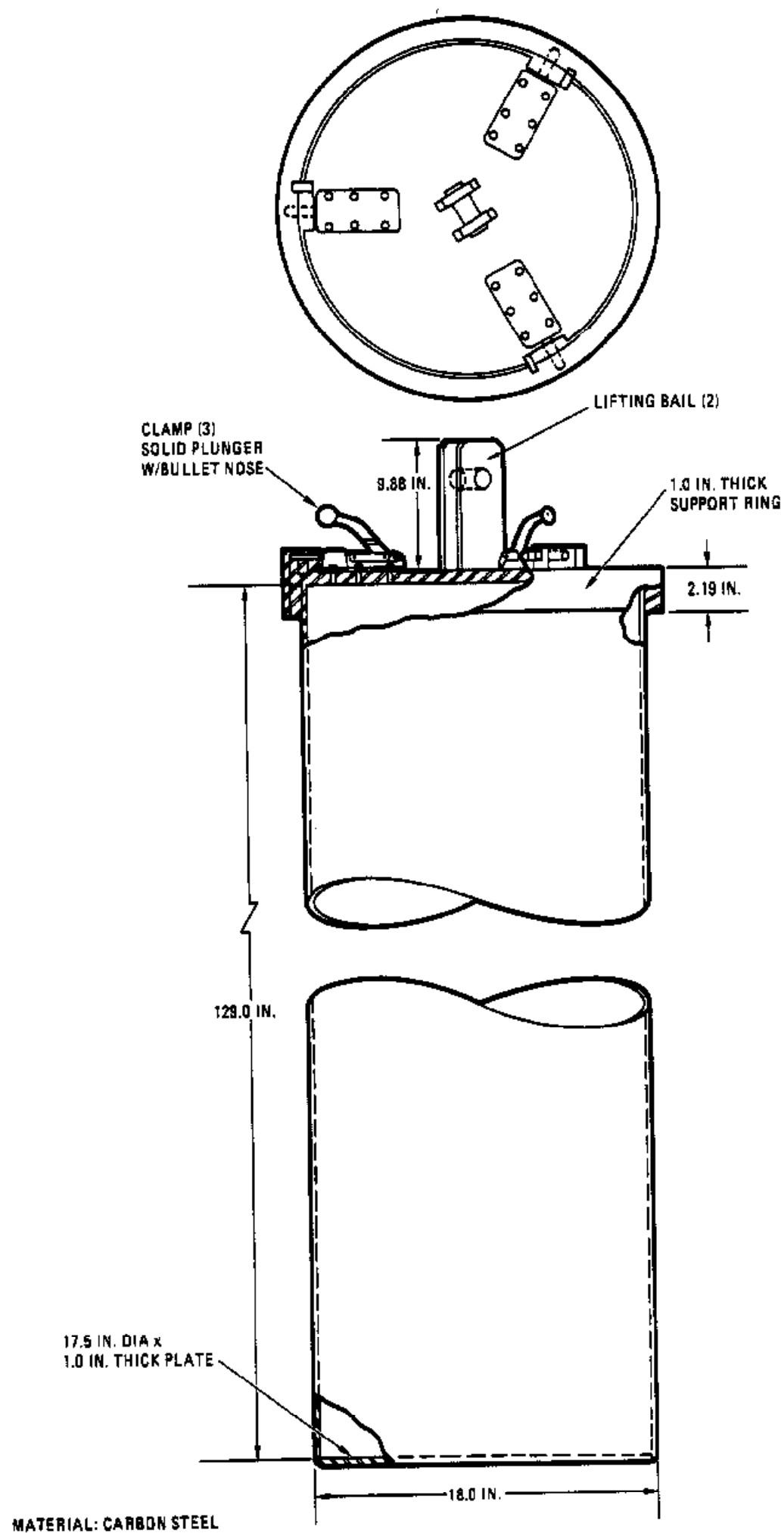


Fig. 3-13. Core 2 storage canister

4. CURRENT INVENTORY

The PB Unit 1 reactor was shutdown on October 31, 1974 and all of the spent fuel was shipped to storage. The total inventory of spent fuel from the reactor consists of two cores, Core 1 and Core 2, some replacement elements, and a number of test elements. All of these have been described in Section 3. A total of 819 fuel elements were irradiated in Core 1, 818 regular elements and one test element. A total of 820 fuel elements were irradiated in Core 2, 787 regular elements and 33 test elements.

Most of the spent fuel is stored at INEL. Some of the test elements and regular elements were shipped to ORNL and GA for postirradiation examination.* All the spent fuel shipped to GA has subsequently been shipped to INEL for storage. The disposition of the spent fuel shipped to ORNL is unknown to us, therefore, this report addresses only the fuel which is currently at INEL, approximately 98% of all the spent fuel from PB Unit 1.

The data received from INEL (Ref. 26) on the PB spent fuel does not allow a detail inventory of each element by serial number or type. The elements are stored in groups of 18 or less. Table 4-1 is the listing received from INEL on Core 1 which includes 814 elements (813 regular elements and one test element) shipped from Philadelphia Electric. Core 1 is currently stored in open-field drywells at the ICPP Fermi I Blanket Storage Facility at INEL. Table 4-2 is the listing on Core 2

*At one point in time, 30 elements (23 test and 7 fuel) were shipped to ORNL, and 21 elements (7 test and 14 fuel) were shipped to GA. Further whereabouts of these elements can be determined from the shipping records at each of the sites. For detailed information on the accounting of these fuel elements, refer to Appendix A.

TABLE 4-1
PEACH BOTTOM UNIT 1 - CORE 1 INVENTORY AT INEL

Silo Number	Basket Number	Uranium (gm)	U-235 (gm)	Quantity (elements)
1	42	4823	3667	18
2	7	4919	3804	18
3	-	4972	3890	18
4	4	4719	3574	18
5	6	4960	3884	18
6	14	4857	3718	18
7	3	4761	3621	18
8	13	4815	3738	18
9	15	4662	3516	18
10	48	4705	3623	18
11	24	4804	3643	18
12	38	4777	3593	18
13	8	4822	3687	18
14	10	4939	3854	18
15	12	4814	3679	18
16	25	4794	3685	18
17	5	4749	3672	18
18	1	4853	3847	18
19	30	4335	3216	18
20	22	4309	3176	18
21	18	4519	3414	18
22	20	4776	3599	18
23	16	4865	3721	18
24	23	4840	3681	18
25	36	4884	3755	18
26	35	4957	3869	18
27	39	4835	3751	18
28	43	4823	3709	18
29	33	4919	3871	18
30	40	4780	3712	18
31	37	4253	3185	18
32	27	3442	2352	18
33	21	3480	2425	18
34	31	3482	2444	18
35	17	2805	1754	18
36	26	3785	2721	18
37	32	4879	3760	18
38	44	4923	3848	18
39	34	4702	3612	18
40	49	4744	3624	18
41	11	4687	3546	18
42	9	2932	1869	18
43	41	4099	2950	18
44	28	4836	3680	18
45	29	4874	3738	18
46	45	1084	842	4
				814 (total)

TABLE 4-2
PEACH BOTTOM UNIT 1 - CORE 2 INVENTORY AT INEL

Uranium (gm)	U-235 (gm)	Quantity	Type
3053	618	18 elements	Peach Bottom
2355	657	18 elements	Peach Bottom
1854	678	18 elements	Peach Bottom
1855	680	18 elements	Peach Bottom
2470	623	18 elements	Peach Bottom
3184	468	18 elements	Peach Bottom
2446	570	18 elements	Peach Bottom
2508	562	18 elements	Peach Bottom
2449	570	18 elements	Peach Bottom
2657	565	18 elements	Peach Bottom
2441	548	17 elements	Peach Bottom
2722	562	18 elements	Peach Bottom
2833	539	18 elements	Peach Bottom
2790	567	18 elements	Peach Bottom
2919	551	18 elements	Peach Bottom
2995	594	18 elements	Peach Bottom
2997	610	18 elements	Peach Bottom
3004	610	18 elements	Peach Bottom
3001	609	18 elements	Peach Bottom
3027	605	18 elements	Peach Bottom
3038	610	18 elements	Peach Bottom
3017	614	18 elements	Peach Bottom
3033	617	18 elements	Peach Bottom
3091	617	18 elements	Peach Bottom
3009	611	18 elements	Peach Bottom
3034	615	18 elements	Peach Bottom
3099	620	18 elements	Peach Bottom
3136	624	18 elements	Peach Bottom
3037	604	18 elements	Peach Bottom
3046	584	18 elements	Peach Bottom
2977	580	18 elements	Peach Bottom
2983	540	18 elements	Peach Bottom
2978	548	18 elements	Peach Bottom
2975	580	18 elements	Peach Bottom
2958	582	18 elements	Peach Bottom
2972	607	18 elements	Peach Bottom
2948	607	18 elements	Peach Bottom
2975	595	18 elements	Peach Bottom
2971	594	18 elements	Peach Bottom
2971	594	18 elements	Peach Bottom
2976	578	18 elements	Peach Bottom
2978	578	18 elements	Peach Bottom
2152	373	13 elements	Peach Bottom
2787	496	17 elements	Peach Bottom
		785 (total)	

which accounts for 785 elements shipped from Philadelphia Electric. Core 2 was placed in the Irradiated Fuel Storage Facility at INEL. Additional information was provided to INEL by Philadelphia Electric for Core 1 (Ref. 26).

5. BURNUP ANALYSIS AND ISOTOPIC COMPOSITION

This section provides available data on burnup analysis and isotopic composition of the PB Unit 1 spent fuel. Data on initial heavy metal loadings are also provided.

5.1. INITIAL HEAVY METAL LOADINGS

5.1.1. Core 1

Four types of fuel elements, based on heavy metal loadings and resultant nuclear properties, were required for the PB reactor. These elements, designated types 1, 2, 3, and 4 are in turn loaded with four types of fuel compacts and burnable poison spines as appropriate. The resultant heavy metal loadings are given in Table 5-1. The arrangement of the different compact types is given in Table 5-2 and the four types of compact loadings, labeled A, B, C, and D are listed in Table 5-3. Each compact is approximately 3 in. long; 30 such compacts make up the 90-in. long fuel midsection of each fuel element.

5.1.2. Core 2

Core 2 also utilized four types of fuel elements based on heavy metal loadings on resultant nuclear properties. The actual initial heavy metal loadings for Core 2 were lower than Core 1. Table 5-4 gives the element loadings for each fuel type. The arrangement of compact types are the same as given in Table 5-2 for Core 1 and the reduced compact loading are given in Table 5-5.

TABLE 5-1
CORE 1 FUEL ELEMENT INITIAL HEAVY METAL LOADINGS (g)

Isotope	Fuel Element Type			
	1	2	3	4
Th-232	1563.0	1563.0	1563.0	3460.8
U-234	4.68	4.68	4.68	2.46
U-235	291.0	291.0	291.0	154.2
U-236	1.56	1.56	1.56	0.84
U-238	15.15	15.15	15.15	8.04
Rh-103(a)	18.50	6.16	6.16	0
Carbon(b)	8550.0	8550.0	8550.0	8190.0
Boron(c)	0	0	18.3	0

(a) Rhodium was used in these fuels to aid in achieving a prompt negative fuel temperature coefficient of reactivity.

(b) Carbon in fuel compacts only. Additional fuel element carbon is combined in graphite sleeve, reflectors, and spine.

(c) As zirconium diboride.

TABLE 5-2
CORE 1 FUEL ELEMENTS (Ref. 27)

Description	Fuel Element Type			
	1	2	3	4
	Heavy Rhodium	Light Rhodium	Light Rhodium with Burnable Poison	Heavy Thorium, Light Uranium
Spine	Solid graphite	Solid graphite	Hollow with poison	Solid graphite
Compact type:				
In upper 9 in.	A	A	A	D
In middle 54 in.	B	C	C	D
In lower 27 in.	A	A	A	D
Number for nominal core loading	54	564	84	102

TABLE 5-3
CORE 1 FUEL COMPACT INITIAL HEAVY METAL LOADINGS
[Loading per 3 in. of Compact (g)]
(Ref. 28)

Compact Type	A	B	C	D
Description	Standard	Heavy Rhodium	Light Rhodium	Heavy Thorium
Th-232	52.10	52.10	52.10	115.36
U-234(a) (maximum)	0.156	0.156	0.156	0.082
U-235	9.70	9.70	9.70	5.14
U-236(a) (maximum)	0.052	0.052	0.052	0.028
U-238	0.505	0.505	0.505	0.268
Rh-103	0	1.028	0.342	0
Carbon	285.00	285.00	285.00	273.00

(a) U-234 and U-236 loadings are not required. These are the maximum amounts expected in the fully enriched feed material.

TABLE 5-4
CORE 2 FUEL ELEMENT INITIAL HEAVY METAL LOADINGS (g)
(Ref. 27)

Isotope	Fuel Element Type			
	1	2	3	4
Uranium (93% enriched)	249.6	249.6	249.6	140.7
Thorium-232	1374.0	1374.0	1374.0	2598.0
Boron	0	0	18.31	0
Rhodium	18.54	6.16	6.16	0

TABLE 5-5
CORE 2 FUEL COMPACT INITIAL HEAVY METAL LOADINGS
[Loading per 3 in. of Compact (g)]
(Ref. 27)

	Compact Type			
	A (Standard)	B (Heavy Rhodium)	C (Light Rhodium)	D (Heavy Thorium)
Thorium-232	45.8	45.8	45.8	86.6
Uranium (93% enriched)	8.32	8.32	8.32	4.69
Rhodium	0	1.03	0.342	0

5.2. FUEL BURNUP

Core 1 was irradiated to 451 EFPD, and Core 2 to 897 EFPD, as compared to the designed core lifetime of the fuel of 900 EFPD. The burnup data for each of the two cores is summarized in Table 5-6.

5.3. FUEL ACCOUNTABILITY

5.3.1. Core 1

Table 5-7 provides a summary of the postirradiation fuel loadings for Core 1 for each of the package types previously described in Table 3-4. The data is provided for average and maximum loadings of uranium. Table 5-8 provides a summary for the 813 regular fuel elements of the postirradiation fuel loadings including a small amount of plutonium.

Data on specific elements loadings were provided to INEL by Philadelphia Electric in Ref. 29. The elements were identified by canister cap number and package type (as defined in Table 3-4).

5.3.2. Core 2 - Regular Fuel Elements

As was seen in Table 5-4, Core 2 has two basic initial uranium and thorium loadings. The postirradiation loading can be summarized in two sets of average and maximum loadings, one for fuel types 1, 2, and 3 and another for fuel type 4. Table 5-9 provides this summary.

Specific elements heavy metal loadings by serial number are available in hard copy at GA but not on computer tape or disk. This data was sent to INEL as part of the shipping records.

Table 5-10 provides the end-of-cycle heavy metal loadings for the entire Core 2.

TABLE 5-6
BURNUP DATA FOR PEACH BOTTOM CORES

	Core 1	Core 2
EFPD	451.5	897.4
MW(t)-h(a)	1,246,089	2,476,454
Shutdown date	October 3, 1969	October 31, 1974
Nominal core		
Heavy metal loading	1,686.14 kg	1,418.6 kg
Burnup	30,795 MW-d/MTHM	72,717 MW-d/MTHM

(a) Reactor core output 115 MW(t)

TABLE 5-7
CORE 1 SUMMARY OF POSTIRRADIATION URANIUM LOADINGS PER ELEMENT BY FUEL PACKAGE TYPE

Package Type	No. of Elements	Total U Average (g) Maximum (g)	U-232 Average (ug) Maximum (ug)	U-233 Average (g) Maximum (g)	U-234 Average (g) Maximum (g)	U-235 Average (g) Maximum (g)	U-236 Average (g) Maximum (g)	U-238 Average (g) Maximum (g)
1	528	268.68 303.81	1645 2081	23.99 27.10	3.71 3.89	206.46 268.84	18.46 20.76	16.06 17.10
2	58	267.46 283.83	1697 2081	24.39 27.10	3.73 3.89	204.46 226.93	18.84 20.76	16.04 16.27
3	7	279.24 282.79	883 960	17.94 19.04	3.47 3.49	227.35 230.81	14.08 14.52	16.39 16.50
4	1	256.77 256.77	1584 1584	20.42 20.42	3.71 3.71	197.31 197.31	19.06 19.06	16.27 16.27
5	1	280.85 280.85	820 820	18.24 18.24	3.44 3.44	229.11 229.11	13.75 13.75	16.31 16.31
6	1	255.80 255.80	1699 1699	21.36 21.36	3.75 3.75	194.85 194.85	19.62 19.62	16.21 16.21
7	1	278.49 278.49	1191 1191	22.71 22.71	3.53 3.53	219.86 219.86	16.25 16.25	16.14 16.14
8	1	297.20 297.20	285 285	11.00 11.00	3.36 3.36	257.31 257.31	8.60 8.60	16.93 16.93
9	71	269.79 295.62	1594 2050	23.67 27.04	3.68 3.86	208.20 258.37	18.15 20.33	16.08 16.71
10	8	268.23 274.76	1836 2050	25.70 27.04	3.77 3.86	203.54 213.19	19.27 20.33	15.96 16.05
11	1	272.57 272.57	1646 1646	25.21 25.21	3.69 3.69	209.35 209.35	18.31 18.31	16.00 16.00
12	1	274.64 274.64	1498 1498	24.36 24.36	3.63 3.63	212.99 212.99	17.61 17.61	16.05 16.05
13	1	285.85 285.85	749 749	17.82 17.82	3.42 3.42	235.34 235.34	12.87 12.87	16.40 16.40
14	98	150.41 155.48	3009 3262	34.81 36.28	3.19 3.34	91.69 96.02	11.90 12.33	8.81 8.86
15	5	268.15 277.75	1715 2013	24.53 25.57	3.73 3.84	205.07 218.51	18.79 20.25	16.03 16.13
16	1	288.17 288.17	651 651	16.82 16.82	3.40 3.40	239.07 239.07	12.35 12.35	16.53 16.53
17	1	277.75 277.75	1279 1279	23.04 23.04	3.55 3.55	218.51 218.51	16.51 16.51	16.13 16.13
18	18	270.69 283.63	1550 2013	23.62 25.61	3.66 3.84	209.37 226.63	17.95 20.25	16.09 16.24
19	3	277.57 278.54	1228 1297	22.79 23.00	3.54 3.57	218.63 219.94	16.46 16.90	16.14 16.14
20	3	268.61 284.63	1378 1559	21.33 22.54	3.61 3.68	210.09 227.42	17.35 18.55	16.23 16.26
21	4	150.60 155.48	2933 3240	34.56 36.17	3.16 3.18	92.24 96.02	11.81 11.96	8.82 8.83

TABLE 5-8
SUMMARY OF TOTAL POSTIRRADIATION FUEL LOADINGS FOR
813 ELEMENTS FROM CORE 1

Isotope	Calculated Weights/Concentrations
U-232	1.46 g
U-233	20,523.82 g
U-234	2,956.24 g
U-235	156,518.24 g
U-236	14,266.21 g
U-238	12,324.92 g
U-total	206,593.89 g
Pu-239	411.17 g
Pu-240	82.85 g
Pu-241	63.34 g
Pu-242	8.31 g
Pu-total	565.67 g
Pu-fissile	474.51 g
Pu-fissile/Pu-total	83.88%
Thorium	1,439.31 kg
U-232	7.08 ppm
U-235/U-total	75.76%
(U-233 and U-235)/U-total	85.70%

TABLE 5-9
POSTIRRADIATION HEAVY METAL LOADINGS OF CORE 2
FUEL ELEMENT TYPES, g

Heavy Metal	Types 1, 2, and 3	Type 4
U-233		
Average	33.0	37.8
Maximum	35.2	39.1
U-235		
Average	90.0	36.0
Maximum	189.0	108.4
U-total		
Average	167.0	105.0
Maximum	228.7	108.4
Thorium	1310	2524
Pu-239	0.27	0.08
Pu-240	0.09	0.03
Pu-241	0.15	0.05
Pu-242	0.07	0.03
Pu-total	0.59	0.18

TABLE 5-10
CORE 2 POSTIRRADIATION
TOTAL CORE HEAVY METAL LOADINGS
(December 31, 1974)

Nuclide	Data	Totals
Th-232	kg	1,172.54
Pa-231	Milligrams	5,858.77
Pa-233	Grams	305.47
U-232	Milligrams	7,484.56
U-233	Grams	25,945.99
U-234	Grams	4,546.84
U-235	Grams	66,962.86
U-236	Grams	21,116.46
U-238	Grams	9,252.53
Np-239	Milligrams	0
Pu-239	Milligrams	199,505.53
Pu-240	Milligrams	69,211.53
Pu-241	Milligrams	112,470.13
Pu-242	Milligrams	53,696.54
Np-237	Grams	1,624.52
Rh-103	Grams	2,763.79
B-10	Grams	1.93
U	Grams	127,832.20
U-235	Weight fraction	0.5238
U-233	Weight fraction	0.2030
U-232	ppm	58.55

5.3.3. Core 2 - Test Elements

Heavy metal weights have been tabulated for PB Core 2 test elements. Table 5-11 lists the preirradiation loadings and Table 5-12 lists the postirradiation loadings.

5.4. FISSION PRODUCT INVENTORY (REF. 25)

Table 5-13 summarizes the expected fission product inventory for a fuel element* assuming full exposure. The activities presented in Table 5-13 represent the maximum fission product activity that can be expected in the fuel for a 120-day-cooled fuel element. Data on actual fission product inventories for each fuel element based on its exposure in the core was not available for PB.

5.5. DECAY HEAT

Figure 5-1 shows the calculated decay heat for PB fuel as a function of decay time.

*Refers to a design basis element as noted in Ref. 25.

TABLE 5-11
CORE 2 TEST ELEMENT INITIAL HEAVY METAL LOADINGS (gm)

Test Element Number	Thorium	Uranium ^(a)
PTE-2	2152.62	450.0
FBTE-1	1263.6	215.9
FBTE-2	566.6	235.0
FBTE-3	762.2	194.2
FBTE-4	943.7	235.7
FBTE-5	1518.1	194.4
FBTE-6	1667.7	181.0
FTE-1	1537.8	206.1
FTE-2	1639.5	184.4
FTE-5	1082.4	203.3
RTE-2	804.0	211.9
RTE-4	1093.2	177.4
RTE-5	1083.5	186.6
RTE-6	928.2	190.6
RTE-7	1250.0	185.5
RTE-8	881.1	185.7
FPTE-1	0	1477.5 (9.15% enriched)
FTE-3	996.80	205.9
FTE-4	1027.63	188.42
FTE-6	855.43	222.94
FTE-7	1396.08	223.44
FTE-8	519.15	182.44
FTE-9	1114.5	179.76
FTE-10	685.1	171.81
FTE-11	891.02	224.14
FTE-12	1338.6	191.52
FPTE-3	0	1592.39 (14.08% enriched)
FTE-13	1352.03	99.94
	Pu-total	Pu-239
	18.77	16.65
FTE-14	1922.6	191.5
FTE-15	1883.7	191.85
FTE-16	1045.0	144.93
FTE-17	907.2	100.8
FTE-18	736.2	168.0 (86.46% enriched)

(a) 93.15% enriched except as noted.

TABLE 5-12
CORE 2 TEST ELEMENT POSTIRRADIATION HEAVY METAL LOADINGS (gm)(a)

	Th-232	Pa-231	U-232	U-233(b)	U-234	U-235	U-236	U-238	Pu-239(c)	Pu-240	Pu-241	Pu-242	Np-237
PTE-2	2120.76	0.010	0.003	26.34	5.14	316.77	24.34	23.65	0.80	0.17	0.10	0.009	0.93
FBTE-1	1211.22	0.007	0.008	30.03	4.96	83.11	23.83	8.93	0.26	0.09	0.14	0.060	2.03
FBTE-2	526.21	0.003	0.004	16.88	4.00	87.36	26.26	9.76	0.25	0.09	0.14	0.069	2.14
FBTE-3	727.09	0.004	0.005	19.00	3.93	67.71	22.03	8.12	0.19	0.06	0.11	0.058	1.73
FBTE-4	932.78	0.003	(d)	9.64	3.44	179.16	9.78	10.97	0.28	0.05	0.02	0.001	0.26
FBTE-5	1457.91	0.008	0.011	32.04	5.39	65.95	22.64	7.98	0.20	0.07	0.12	0.066	1.99
FBTE-6	1650.59	0.005	0.001	14.67	2.92	131.30	8.53	8.41	0.20	0.04	0.02	0.002	0.23
FTE-1	1522.48	0.005	0.001	13.40	3.21	150.84	9.49	9.58	0.23	0.05	0.02	0.002	0.26
FTE-2	1614.40	0.007	0.003	20.36	3.24	120.73	11.44	8.37	0.25	0.06	0.04	0.005	0.46
FTE-5	1039.43	0.005	0.007	23.36	4.47	72.43	22.85	8.52	0.20	0.07	0.11	0.059	1.77
RTE-2	773.80	0.004	0.004	19.43	3.75	98.30	20.55	9.07	0.27	0.09	0.12	0.036	1.43
RTE-4	1072.56	0.005	0.002	16.10	2.95	110.60	11.97	8.00	0.23	0.06	0.05	0.007	0.52
RTE-5	1022.46	0.006	0.008	25.16	4.61	61.57	21.90	7.65	0.19	0.07	0.11	0.065	1.94
RTE-6	882.06	0.005	0.007	23.66	4.57	60.31	22.70	7.78	0.19	0.07	0.12	0.069	2.05
RTE-7	1235.16	0.004	0.001	12.78	2.89	135.34	8.71	8.60	0.22	0.04	0.02	0.002	0.25
RTE-8	837.34	0.005	0.007	22.51	4.38	58.99	22.09	7.58	0.19	0.06	0.11	0.067	1.99
FPTE-1	0	0	0	0	0	107.64	5.65	1330.60	6.65	1.18	0.58	0.041	1.13
FTE-3	990.41	0.002	(d)	6.00	1.54	170.22	5.13	11.75	0.20	0.02	0.005	(d)	0.08
FTE-4	1006.65	0.004	0.003	15.51	2.00	107.05	13.84	10.21	0.25	0.07	0.08	0.015	0.60
FTE-6	825.61	0.004	0.004	18.93	2.70	99.77	21.47	11.53	0.32	0.10	0.15	0.049	1.43
FTE-7	1359.43	0.006	0.006	23.34	3.07	100.27	21.05	11.74	0.27	0.09	0.13	0.044	1.23
FTE-8	499.05	0.002	0.002	12.67	2.02	80.83	17.31	9.58	0.22	0.07	0.10	0.037	1.01
FTE-9	1080.01	0.006	0.005	22.36	2.67	83.79	16.80	9.34	0.26	0.08	0.12	0.036	1.08
FTE-10	658.36	0.003	0.003	16.89	2.29	76.55	16.58	8.89	0.24	0.08	0.11	0.038	1.10
FTE-11	858.50	0.004	0.005	19.79	2.93	93.23	22.56	11.55	0.29	0.10	0.15	0.057	1.54
FTE-12	1301.92	0.007	0.006	23.94	2.83	90.26	17.75	9.96	0.28	0.09	0.12	0.037	1.13
FPTE-3	0	0	0	0	0	112.59	21.18	1337.45	7.15	2.26	3.05	0.933	1.19
FTE-13	1317.24	0.006	0.005	23.69	2.16	50.05	8.81	4.36	1.08	2.03	1.92	1.002	0.47
FTE-14	1889.32	0.007	0.002	27.83	3.51	132.15	10.45	8.69	0.23	0.05	0.03	0.003	0.35
FTE-15	1834.43	0.008	0.005	34.63	4.46	104.64	15.51	8.45	0.20	0.06	0.08	0.017	0.73
FTE-16	1018.51	0.005	0.003	18.45	2.88	75.85	12.35	6.31	0.17	0.05	0.06	0.015	0.67
FTE-17	881.11	0.004	0.003	17.70	2.41	50.00	9.01	4.37	0.11	0.04	0.05	0.012	0.51
FTE-18	712.83	0.003	0.003	15.54	4.91	75.75	15.12	14.48	0.37	0.12	0.16	0.046	0.91

(a) Assuming all test elements stay in Core 2 until Core 2 end-of-life (EOL).

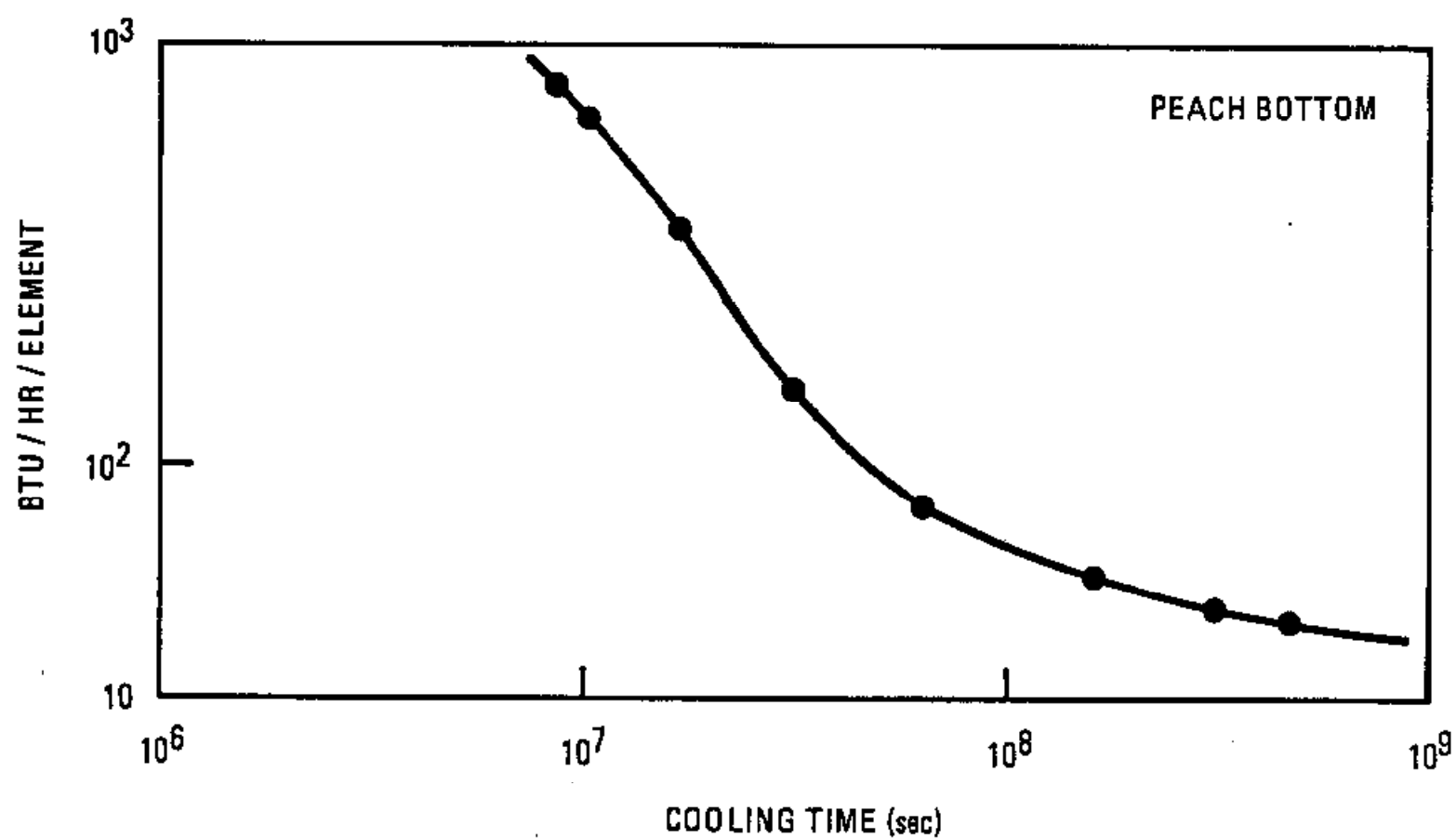
(b) Includes Pa-233.

(c) Includes Np-239.

(d) Less than 0.001.

TABLE 5-13
PEACH BOTTOM FUEL ELEMENT FISSION PRODUCT INVENTORY
(900 Equivalent-Full-Power-Days, 120-Day Cooled)

Isotope	Activity (Curies)
Kr-85	5×10^1
Sr-89	1.17×10^3
Sr-90	3.93×10^2
Y-90	3.93×10^2
Y-91	1.73×10^3
Zr-95	2.1×10^3
Nb-95	3.98×10^3
Ru-103	4.8×10^2
Rh-103m	4.8×10^2
Ru-106	4×10^2
Rh-106	4×10^2
Te-127m	2.2×10^1
Te-127	2.2×10^1
Te-129m	3.1×10^1
Te-129	3.1×10^1
Cs-137	6×10^2
Ba-137	6×10^2
Ba-140	1.8
La-140	2
Ce-141	6.35×10^2
Pr-143	1.9×10^1
Ce-144	5.06×10^3
Pr-144	5.06×10^3
Pm-147	1.5×10^3
Sm-151	1.3×10^1
Pa-233	2.2×10^4
U-233	4.2×10^{-1}
U-234	4.65×10^{-2}
Pu-238	9.5
Pu-239	2.69×10^{-2}
Pu-240	2.3×10^{-2}
Pu-241	2×10^1
Total	25.4×10^3



Peach Bottom HTGR

Fig. 5-1. Heat generation rate as a function of cooling time

6. REFERENCES

1. Scheffel, W. J., B. F. Disselhorst, and S. Langer, "Fort St. Vrain Proof Test Element Number Two Design, Fabrication, and Assembly Report," USAEC Informal Report Gulf-GA-B12340, Gulf General Atomic, May 21, 1973.
2. Scheffel, W. J., "Design and Operational Evaluation for Fuel Test Elements No. 14 and 15," USAEC Informal Report Gulf-GA-B12344, Gulf General Atomic, November 3, 1972.
3. Scheffel, W. J., "Phase III - Final Progress Report, Part I of Two Parts, Design and Operational Evaluation for the Plutonium Test Element (FTE-13)," Gulf General Atomic Report Gulf-GA-B12271, August 18, 1972.
4. Scheffel, W. J., et al., "Phase III - Final Progress Report, Part II of Two Parts, Design and Fabrication of the Plutonium Fuels for the Plutonium Fuel Test Element (FTE-13)," Gulf General Atomic Report Gulf-GA-B12288, August 22, 1972.
5. Sanders, C. F., and J. D. Sease, "Fabrication and Characteristics of Plutonium Test FTE-13: An HTGR Test Element Containing PuO_{2-x} , $\text{Th}_{0.25}\text{Pu}_{0.25}\text{O}_{2-x}$, and ThO_2 ," USAEC Report ORNL-TM-4207, Oak Ridge National Laboratory, August 1973.
6. Wallroth, C. F., et al., "Thermal, Nuclear, and Fission Product Evaluation of Fuel Pin Test Element FPTE-1 and FPTE-3," General Atomic Report GA-A13849, December 1980.
7. Christie, G. E., "The Irradiation of MK3 HTR Fuel in Peach Bottom HTGR Reactor, Irradiation History of Main Experiment - IE 486/3," UKAEA Report TRG 2748(S), February 1976.
8. Wallroth, C. F., et al., "Postirradiation Examination of Peach Bottom Fuel Test Element FTE-3," USAEC Report GA-A13004, General Atomic, August 15, 1974.

9. Wallroth, C. F., et al., "Postirradiation Examination of Peach Bottom Fuel Test Element FTE-4," General Atomic Report GA-A13452, July 1977.
10. Wallroth, C. F., et al., "Postirradiation Examination of Peach Bottom Fuel Test Element FTE-18," General Atomic Report GA-A13699, June 1976.
11. Fitzgerald, C. L., et al., "Head-End Reprocessing Studies with Irradiated HTGR-Type Fuels: III. Studies with RTE-7: TRISO UC₂ - TRISO ThC₂," ERDA Report ORNL-5090, Oak Ridge National Laboratory, November 1975.
12. Morissette, R. P., and K. P. Steward, "Recycle Test Element Program Design, Fabrication, and Assembly," Gulf General Atomic Report GA-10109, September 1971.
13. Long, E. L., Jr., R. B. Fitts, and F. J. Homan, "Fabrication of ORNL Fuel irradiated in the Peach Bottom Reactor and Postirradiation Examinations of Recycle Test Elements 7 and 4," USAEC Report ORNL-TM-4477, Oak Ridge National Laboratory, September 1974.
14. Saurwein, J. J., et al., "Final Report on the Peach Bottom Test Element Program," GA-A15999, UC-77, GA Technologies Inc., November 1982.
15. Disselhorst, B. F., "Peach Bottom Fuel Element Review," Internal Memo, May 13, 1966.
16. Steward, K. P., "Spine Samples in the Phase 1 and Phase 2 Peach Bottom Test Elements," Internal Memo GA-P-913-5, September 30, 1971.
17. Scheffel, W. J., et al., "Operating History Report for the Peach Bottom HTGR," General Atomic Report GA-A13907, Vol. 1, August 31, 1976.
18. Dyer, F. F., R. P. Wichner, W. J. Martin, L. L. Fairchild, R. J. Kedl, and H. J. de Nordwall, "Postirradiation Examination of Peach Bottom HTGR Driver Fuel Element E06-01," Report ORNL-5126, Oak Ridge National Laboratory, March 1976.
19. Wichner, R. P., F. F. Dyer, W. J. Martin, and L. C. Bate, "Distribution of Fission Products in Peach Bottom HTGR Fuel Element E11-07," Report ORNL-5214, Oak Ridge National Laboratory, April 1977.

20. Wichner, R. P., F. F. Dyer, and W. J. Martin, "Distribution of Fission Products in Peach Bottom HTGR Fuel Element E14-01," Report ORNL/TM-5730, Oak Ridge National Laboratory, August 1977.
21. Dyer, F. F., R. P. Wichner, W. J. Martin, and L. L. Fairchild, "Distribution of Fission Products in Peach Bottom HTGR Fuel Element F03-01," Report ORNL/TM-5996, Oak Ridge National Laboratory, June 1978.
22. Wichner, R. P., F. F. Dyer, W. J. Martin, and L. L. Fairchild, "Distribution of Fission Products in Peach Bottom HTGR Fuel Element E01-01," Report ORNL/TM-6353, Oak Ridge National Laboratory, August 1978.
23. Wichner, R. P., F. F. Dyer, W. J. Martin, and L. L. Fairchild, "Distribution of Fission Products in Peach Bottom HTGR Fuel Element E05-05," Report ORNL/TM-6455, Oak Ridge National Laboratory, January 1979.
24. Agreement between USAEC and Philadelphia Electric Company for Master Terms and Conditions for Financial Settlement for Spent Fuels Appendix A to Contract No. AT(10-1)-1314, March 1971.
25. Anderson, P. A., and H. S. Meyer, "Dry Storage of Spent Nuclear Fuel," NUREG/CR-1223, Exxon Nuclear Idaho Company, Inc., April 1980.
26. Letter No. RRDD-71-86, R. D. Denney, Westinghouse, Idaho Nuclear Company, Inc. to N. Tomsio, GA Technologies Inc., April 30, 1986.
27. Peach Bottom Atomic Power Station Unit 1, Core 2 Design and Operational Evaluation, Proposed Facility Change and Technical Specification Change (No. 13), Philadelphia Electric Company, January 1970.
28. Application of Philadelphia Electric Company for Construction Permit and Class 104 License, Part C Final Hazards Summary Report, Peach Bottom Atomic Power Station, Vol. II - Plant Description and Safeguards Analysis (Sections I and II).
29. Letter, R. J. Conti, Philadelphia Electric Company to Jack Hammond, Allied Chemical Corporation, September 7, 1971.

APPENDIX A
PEACH BOTTOM SPENT FUEL INVENTORY

TABLE A-1
PEACH BOTTOM CORE 1 SPENT FUEL INVENTORY

Fuel Elements

New fuel ^(a) shipped from GA	868
Unirradiated fuel reprocessed at GA ^(b)	-47
Irradiated fuel shipped to GA ^(c)	-1
Spent fuel stored at INEL ^(d)	<u>-814</u>
	6
	(fuel unaccounted for)

(a) Not included is test element PTE-1 which was shipped to Idaho on November 18, 1975.

(b) Shipped on June 2, 1970.

(c) Shipped on October 20, 1970.

(d) Idaho National Engineering Laboratory.

TABLE A-2
PEACH BOTTOM CORE 2 SPENT FUEL INVENTORY

Fuel Elements

New fuel shipped from GA	862
Rejects shipped to GA ^(a)	-12
Irradiated fuel shipped to GA ^(b)	-1
Spent fuel stored at INEL ^(c)	-783
Unirradiated fuel reprocessed at UNC ^(d)	-59
Elements ^(e) shipped to ORNL	<u>-7</u>
	0

(all fuel accounted for)

(a) Eight elements were shipped on June 2, 1970 and four elements were shipped on July 28, 1970.

(b) Shipped on August 6, 1971.

(c) Idaho National Engineering Laboratory.

(d) United Nuclear Corporation, Rhode Island. Shipped on June 28, 1974.

(e) Elements listed on Table A-4.

TABLE A-3
PEACH BOTTOM CORE 2 SPENT TEST FUEL INVENTORY

Test Elements

Original number of test elements	33
Shipped to GA(a)	-6
Disposed at GA(b)	-1
Shipped to INEL(c)	-3
Shipped to ORNL(d)	-14
Shipped from GA Hot Cell to ORNL(e)	-6
Postirradiation studies at ORNL(f)	<u>-3</u>
	0

(all fuel accounted for)

(a) Elements listed on Table A-5.

(b) Test element PTE-2 was disposed after a postirradiation examination was performed.

(c) Idaho National Engineering Laboratory. Two test elements (FBTE-4 and FBTE-6) are stored in the Irradiated Fuel Storage Facility. Test element FTE-10 was shipped on February 3, 1977.

(d) Elements listed on Table A-6.

(e) Elements listed on Table A-7. Documented in: GA Letter C. F. Wallroth to V. C. A. Vaughen, "Shipment of Peach Bottom Fuel Rods to ORNL," FTEB-292-CFW-77, October 31, 1977.

(f) Test element RTE-6 through RTE-8 are documented in: Tiegs, T. N., and E. L. Long, Jr., "Postirradiation Examination of Recycle Test Elements from the Peach Bottom Reactor," DOE Report ORNL-5422, Oak Ridge National Laboratory, December 1978.

TABLE A-4
PEACH BOTTOM FUEL ELEMENTS SHIPPED TO ORNL

Item	Serial Number	Shipment Number	Date Shipped
1	886	ZRZ-FZC-2	1/11/73
2	910	ZRZ-FZC-4	2/19/74
3	889	ZRZ-FZC-7	5/06/75
4	547	ZRZ-FZC-9	6/13/75
5	880	ZRZ-FZC-11	9/12/75
6	616	ZRZ-FZC-14	3/23/76
7	908	ZRZ-FZC-16	5/04/76

TABLE A-5
PEACH BOTTOM TEST ELEMENTS SHIPPED FROM
PHILADELPHIA ELECTRIC TO GA

Item	Element Number	Shipment Number	Date Shipped
1	RTE-2	ZRZ-ZGQ-3	06/18/70
2	FPTE-1	ZRZ-ZGQ-7	04/24/72
3	FTE-1	ZRZ-ZGQ-8	08/10/72
4	FTE-2	ZRZ-ZGQ-9	11/14/72
5	FTE-18	ZRZ-ZGQ-10	07/15/75
6	FPTE-3	ZRZ-ZGQ-11	09/25/75

TABLE A-6
PEACH BOTTOM TEST ELEMENTS SHIPPED FROM
PHILADELPHIA ELECTRIC TO ORNL

Item	Element Number	Shipment Number	Date Shipped
1	RTE-4	ZRZ-FZC-3	02/07/73
2	FTE-13	ZRZ-FZC-12	02/10/76
3	RTE-5	ZRZ-FZC-13	02/25/76
4	FTE-11	ZRZ-FZC-15	04/14/76
5	FTE-16	ZRZ-FZC-17	06/07/76
6	FTE-17	ZRZ-FZC-18	08/03/76
7	FBTE-2	ZRZ-FZC-19	09/08/76
8	FTE-7	ZRZ-FZC-20	09/21/76
9	FTE-8	ZRZ-FZC-21	09/30/76
10	FBTE-5	ZRZ-FZC-22	10/18/76
11	FTE-12	ZRZ-FZC-23	10/28/76
12	FTE-9	ZRZ-FZC-24	11/19/76
13	FBTE-1	ZRZ-FZC-25	12/16/76
14	FBTE-3	ZRZ-FZC-26	01/18/77

TABLE A-7
PEACH BOTTOM TEST ELEMENTS SHIPPED FROM
GA HOT CELL TO ORNL

Item	Element Number	Documentation on Postirradiation Studies
1	FTE-3	GA-A13004
2	FTE-4	GA-A13452
3	FTE-5	---
4	FTE-6	GA-A13943
5	FTE-14	GA-A13944
6	FTE-15	GA-A13944

DISTRIBUTION:

	<u>No. of Copies</u>
<u>DOE/HQ</u>	
T. Nguyen	2
<u>DOE/ORO</u>	
S. S. Perkins	2
<u>ORNL</u>	
C. W. Forsberg	1
A. R. Irvine	1
K. J. Notz	5
R. Salmon	1
T. D. Welch	1
Central Files	1
Waste Library	1